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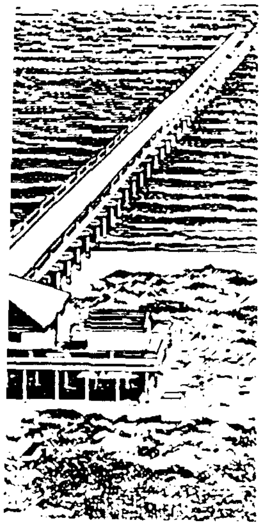
GENERAL INVESTIGATION OF TIDAL INLETS

GITI REPORT 21



STABILITY OF SELECTED UNITED STATES TIDAL INLETS

by

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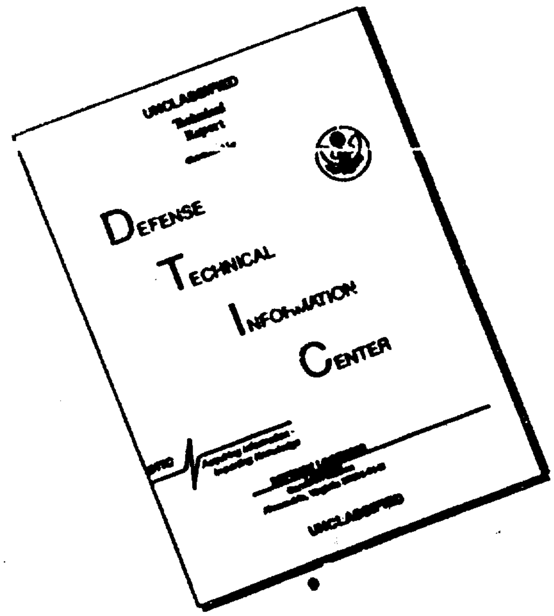

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This report, the 21st in a series under the General Investigation of Tidal Inlets program, summarizes an investigation on the stability of selected US tidal inlets. The study developed methods for describing stability characteristics to be used later in relating the characteristics to the morphology and hydraulics of inlet systems. The methods were applied to analyze the stability of a wide range of inlets in order to develop a database on natural variations in inlet stability, and a possible classification of inlets based on their stability was examined for interrelationships. Regional variation in stability was analyzed. It should be noted that this report does not attempt to relate inlet stability to the morphology or hydraulics of inlet systems. Rather, this report is restricted to analysis of the stability characteristics of inlets.

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PREFACE

This report, the 21st in a series, presents the results of a project on the stability of tidal inlets based on parameters that can be measured from aerial photographs. The research described in this report was part of the General Investigation of Tidal Inlets (GITI), sponsored by Headquarters, US Army Corps of Engineers (HQUSACE). The HQUSACE Technical Monitors were Messrs. John H. Lockhart, Jr.; James G. Housley; James E. Crews; and Robert E. Campbell.

The study was conducted in 1977 in the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES) under the direction of Mr. Henry B. Simmons, former Chief, HL, now retired; Dr. Robert W. Whalin, former Chief, Wave Dynamics Division (WDD), Coastal Engineering Research Center (CERC), now Technical Director, WES; and Mr. Claude E. Chatham, Jr., former Chief, Wave Processes Branch, now Chief, WDD. This report was prepared by Dr. C. Linwood Vincent, former Chief, Coastal Oceanography Branch (COB), Research Division (RD), CERC, now Program Manager; Mr. William D. Corson, formerly with COB, now with the Prototype Measurement and Analysis Branch, Engineering and Development Division, CERC; and Ms. Kathryn J. Gingerich, formerly with the Coastal Processes Branch (CPB), RD, CERC. The work was conducted under the general supervision of Mr. H. Lee Butler, Chief, RD; Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; and Dr. James R. Houston, Chief, CERC.

Final revision and publication of this report were made under the Inlet Stability Work Unit 32526 of the Harbor Entrances and Coastal Channels Program at CERC. Mses. Gingerich and Julie D. Rosati, CPB, were consecutive Principal Investigators of Work Unit 32526 during preparation of the final report under the direct supervision of Mr. Bruce A. Ebersole, Chief, CPB. Mr. Fulton C. Carson and Ms. Carolyn J. Dickson, CPB, prepared the computer-generated figures and assisted with formatting of the final manuscript.

COL Larry B. Fulton, EN, was Commander and Director of WES during publication of this report. Dr. Whalin was Technical Director.

FOREWORD

Over the past 30 years, the US Army Corps of Engineers, through its Civil Works program, has sponsored research into the behavior and characteristics of tidal inlets. The Corps' interest in tidal inlet research stems from its responsibilities for navigation, beach erosion prevention and control, and flood control. Tasked with the creation and maintenance of navigable US waterways, the Corps dredges millions of cubic yards of material each year from tidal inlets that connect the ocean with bays, estuaries, and lagoons. Design and construction of navigation improvements of existing tidal inlets are an important part of the work of many Corps offices. In some cases, design and construction of new inlets are required. Development of information concerning the hydraulic characteristics of inlets is important not only for navigation and inlet stability, but also because inlets, by allowing for the ingress of storm surges and egress of flood waters, play an important role in the flushing of bays and lagoons.

A research program, the General Investigation of Tidal Inlets (GITI), was developed to provide quantitative data for use in design of inlets and inlet improvements. It was designed to meet the following objectives: to determine the effects of wave action, tidal flow, and related phenomena on inlet stability and on the hydraulic, geometric, and sedimentary characteristics of tidal inlets; to develop the knowledge necessary to design effective navigation improvements, new inlets, and sand transfer systems at existing tidal inlets; to evaluate the water transfer and flushing capability of tidal inlets; and to define the processes controlling inlet stability.

The GITI was divided into three major study areas: (a) inlet classification, (b) inlet hydraulics, and (c) inlet dynamics.

a. Inlet classification. The objectives of the inlet classification study were to classify inlets according to their geometry, hydraulics, and stability and to determine the relationships that exist among the geometric and dynamic characteristics and the environmental factors that control these characteristics. The classification study kept the general investigation closely related to real inlets and produced an important inlet database useful in documenting the characteristics of inlets.

b. Inlet hydraulics. The objectives of the inlet hydraulics study were to define tide-generated flow regime and water level fluctuations in the vicinity of coastal inlets and to develop techniques for predicting these phenomena. The inlet hydraulics study was divided into three areas: (1) idealized inlet model study, (2) evaluation of state-of-the-art physical and numerical models, and (3) prototype inlet hydraulics.

(1) The idealized inlet model. The objectives of this model study were to determine the effect of inlet configurations and structures on discharge, head loss, and velocity distribution for a number of realistic inlet shapes and tide conditions. An initial set of tests in a trapezoidal inlet was conducted between 1967 and 1970. However, in order that subsequent inlet models would be more representative of real inlets, a number of "idealized" models representing various inlet morphological classes were being developed and tested. The effects of jetties and wave action on the hydraulics were included in the study.

(2) Evaluation of state-of-the-art modeling techniques. The objectives of this part of the inlet hydraulics study were to determine the usefulness and reliability of existing physical and numerical modeling techniques in predicting the hydraulic characteristics of inlet-bay systems and to determine whether simple tests, performed rapidly and economically, were useful in the evaluation of proposed inlet improvements. Masonboro Inlet, North Carolina, was selected as the prototype inlet that would be used along with hydraulic and numerical models in the evaluation of existing techniques. In September 1969, a complete set of hydraulic and bathymetric data was collected at Masonboro Inlet. Construction of the fixed-bed physical model was initiated in 1969, and extensive tests have been performed since then. In addition, three existing numerical models were applied to predict the inlet's hydraulics. Extensive field data were collected at Masonboro Inlet in August 1974 for use in evaluating the capabilities of the physical and numerical models.

(3) Prototype inlet hydraulics. Field studies at a number of inlets provided information on prototype inlet-bay tidal hydraulic relationships and the effects of friction, waves, tides, and inlet morphology on these relationships.

c. Inlet dynamics. The basic objective of the inlet dynamics study was to investigate the interactions of tidal flow, inlet configuration, and wave action at tidal inlets as a guide to improvement of inlet channels and nearby shore protection works. The study was subdivided into four specific areas: (1) model materials evaluation, (2) movable-bed modeling evaluation, (3) reanalysis of a previous inlet model study, and (4) prototype inlet studies.

(1) Model materials evaluation. This evaluation was initiated in 1969 to provide data on the response of movable-bed model materials to waves and flow to allow selection of the optimum bed materials for inlet models.

(2) Movable-bed model evaluation. The objective of this study was to evaluate the state-of-the-art of modeling techniques, in this

case movable-bed inlet modeling. Since, in many cases, movable-bed modeling was the only tool available for predicting the response of an inlet to improvements, capabilities and limitations of these models needed to be established.

(3) Reanalysis of an earlier inlet model study. In 1957, a report entitled "Preliminary Report: Laboratory Study of the Effect of an Uncontrolled Inlet on the Adjacent Beaches" was published by the Beach Erosion Board (now the Coastal Engineering Research Center (CERC)). A reanalysis of the original data was performed to aid in planning of additional GITI efforts.

(4) Prototype dynamics. Field and office studies of a number of inlets provided information on the effects of physical forces and artificial improvements on inlet morphology. Of particular importance were studies to define the mechanisms of natural sand bypassing at inlets, the response of inlet navigation channels to dredging and natural forces, and the effects of inlets on adjacent beaches.

This report presents a study of tidal inlet stability based on changes in geomorphic parameters that can be measured from aerial photographs. The report contains substantial amounts of inlet geometric data obtained from aerial photos that may be applicable to site-specific studies.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

STABILITY OF SELECTED UNITED STATES TIDAL INLETS

PART I: INTRODUCTION

Objective

1. Safe navigation through tidal entrances requires a channel that neither migrates substantially nor shoals rapidly. Tidal entrances that exhibit such problems require substantial dredging or eventually become candidates for structural improvements to reduce shoaling and confine the channel. Both solutions to the problems of unstable inlet channels are expensive and in many cases have only limited success.

2. The US Army Corps of Engineers has considerable responsibility in the maintenance of navigation through many coastal waterways and, as a result, has great interest in an improved understanding of the physical processes active at tidal inlets. The General Investigation of Tidal Inlets (GITI) was formulated to provide a better understanding of inlets. One concern in the formulation of this research program was to improve the understanding of the stability of tidal inlets and the conditions that create inlet instability. The research summarized in this report is under the GITI subtask entitled "Inlet Classification." A more detailed discussion of the overall GITI research program and the place that the stability research occupies within the program is provided in the Foreword to this report.

3. The objective of this report is to summarize an investigation on the stability of selected US tidal inlets. Five broad tasks were defined. The first task was to develop methods for describing in a quantitative fashion, if possible, stability characteristics that could be used to relate inlet stability to the morphology and hydraulics of inlet systems and to interrelate various aspects of inlet stability. The second task was to apply the methods to analyze the stability of a wide range of inlets in order to develop a data-base on natural variations in inlet stability. The third task was to investigate a possible classification of inlets based on their stability characteristics. The fourth task was the analysis of interrelationships among

various aspects of inlet stability. The final task was the analysis of any regional variation in stability.

4. It should be noted that this report does not attempt to relate inlet stability to the morphology or hydraulics of inlet systems. The GITI program recognized the necessity of such comparisons and intended for such research to be performed after the completion of the three inlet classification tasks, each of which was considered an analysis of basic components of inlet variability. Thus, this report is restricted to analysis of only the stability characteristics of inlets.

Inlets Selected for Study

5. Analysis of inlet stability is essentially the study of the time rate of change of inlet shoal, throat, and channel characteristics and configurations. It is evident that the study becomes more meaningful as the number of times that an inlet has been charted or photographed increases. Because of the availability of aerial photography as opposed to other types of sequential data, a sufficient database for a study of inlet stability is available only with aerial photography if a large number of inlets are to be considered.

6. Inlets selected for study are listed in Table 1. The order of presentation for inlets in all tables herein follows the sequence listed in Table 1. Dates of aerial photography used in the analysis are provided in Appendix A. These inlets were chosen because they typify the range of US tidal inlets and have a fairly large photographic database.

7. It should be noted that restriction of the database to aerial photography limits the stability study to factors that can be measured photogrammetrically. This precludes analyses of depth changes, although general patterns of shoals and channels can be observed. The care that must be taken in analysis and interpretation of photographic data is discussed in a later section.

Table 1

Summary of Aerial Photographic Data

Inlet Number	Inlet Name	Dates Covered	Number of Photographs
1	Moriches, NY	8-44 to 3-71	12
2	Fire Island, NY	5-55 to 5-70	9
3	Brigantine, NJ	3-40 to 6-68	6
4	Corson, NJ	2-40 to 2-71	21
5	Townsend, NJ	4-40 to 4-73	12
6	Hereford, NJ	4-40 to 4-73	10
7	Gargathy, VA	11-49 to 12-72	6
8	Metomkin, VA	5-49 to 10-69	9
9	Wachapreague, VA	11-49 to 2-67	6
10	Oregon, NC	1-45 to 3-75	8
11	Hatteras, NC	1-45 to 4-68	8
12	Beaufort, NC	6-53 to 10-65	5
13	Bogue, NC	5-53 to 10-70	6
14	New Topsail, NC	10-58 to 4-68	5
15	Rich, NC	11-49 to 5-70	10
16	Carolina Beach, NC	3-56 to 2-72	8
17	Lockwoods Folly, NC	11-49 to 3-70	7
18	Shallotte, NC	4-49 to 12-70	11
19	Tubbs, NC	11-49 to 12-70	9
20	Little River, SC	3-38 to 12-72	8
21	Murrells, SC	3-52 to 3-73	6
22	North, SC	12-49 to 3-73	10
23	South Santee, SC	11-41 to 4-68	5
24	Price, SC	11-41 to 4-68	6
25	Capers, SC	3-49 to 10-63	5
26	Dewees, SC	11-41 to 10-63	7
27	Lighthouse, SC	4-49 to 4-68	5
28	Nassau-N, FL	4-51 to 11-70	4
29	Nassau-S, FL	4-51 to 11-70	4
30	Ft. George, FL	8-43 to 11-70	10
31	St. Augustine, FL	2-47 to 10-56	4
32	Matanzas, FL	5-51 to 11-73	6
33	Ponce De Leon, FL	4-49 to 10-67	5
34	Sebastian, FL	3-51 to 11-68	5
35	Boca Raton, FL	3-45 to 3-71	5
36	Hillsboro, FL	3-47 to 4-73	9
37	Redfish, FL	5-52 to 2-70	5
38	Gasparilla, FL	3-51 to 2-70	4
39	Stump, FL	3-51 to 2-70	4
40	Midnight, FL	4-45 to 2-71	5
41	Big Sarasota, FL	2-48 to 12-69	4
42	Longboat, FL	11-51 to 12-70	7
43	Pass A Grille-S, FL	4-45 to 11-69	4

(Continued)

Table 1 (Concluded)

Inlet Number	Inlet Name	Dates Covered	Number of Photographs
44	Pass A Grille-N, FL	4-45 to 11-69	4
45	Clearwater, FL	4-42 to 12-71	7
46	San Luis, TX	1-54 to 3-68	6
47	Bolinas, CA	?-39 to 9-73	8
48	Drakes, CA	6-52 to 4-74	6
49	Siuslaw, OR	4-57 to 9-73	5
50	Siletz, OR	7-39 to 2-76	4
51	Netarts, OR	7-53 to 7-73	4

Report Organization

8. Previous research on tidal inlet stability is summarized in Part II. Part III describes the approach and methodology used in the present study. Part IV presents the data and discusses recent inlet variability. Relative and absolute values for stability indices are presented in Part V. Part VI discusses regional trends in inlet stability, and a summary of the findings is presented in Part VII. Appendix A lists all aerial photographs used in the investigation. Values of the stability indices for each inlet are listed in Appendix B, and graphical displays of data compiled for each inlet are given in Appendix C. Notation used in this report is listed in Appendix D.

PART II: PREVIOUS RESEARCH

9. The stability of tidal inlets has attracted considerable interest and either directly or indirectly has been a motivating influence on most of the technical research involving inlets. A summary of inlet literature is provided in Barwis (1976). Several past approaches to inlet stability research will be briefly reviewed in the following paragraphs.

10. Initial work describing physical processes at tidal inlets was presented by Brown (1928), and an approach to studying tidal inlet stability that is still used today was first discussed by O'Brien (1931). O'Brien's approach uses a relationship between channel cross-sectional area and tidal prism to estimate inlet stability. In O'Brien's relationship, the term "stability" is used to describe an inlet which will remain open and does not directly relate to channel migration or other geographical inlet changes. Escoffier (1940) presents an extension of O'Brien's work that introduces a relationship between channel cross-sectional area and maximum velocity. More recent research which enhances the O'Brien approach is presented in O'Brien (1966), O'Brien and Dean (1972), Jarrett (1976), and Sorenson (1977).

11. The work by O'Brien and Dean (1972) is based on a combination of a one-dimensional, somewhat idealized model of flow in an inlet between a bay and ocean developed by Keulegan (1951) with the empirical tidal prism versus inlet throat cross-sectional area relationship developed by O'Brien (1931), and the critical cross-sectional area versus maximum velocity concept of Escoffier (1940). The stability index β is defined as

$$\beta = \int_{A_C}^{A_E} (V_{max} - V_T)^3 \, dA \qquad (1)$$

where

A_C = critical cross-sectional area

A_E = equilibrium cross-sectional area

V_{max} = maximum velocity

V_T = threshold velocity for sediment movement

The stability index β is essentially a measure of the volume of sediment that an inlet throat can absorb before the critical cross-sectional area is achieved. Once the critical cross-sectional area is exceeded, depositional changes tend toward closure of the inlet.

12. A slightly different approach to estimating inlet stability was described by Bruun and Gerritsen (1960); Bruun (1967); and Bruun, Gerritsen, and Bhakta (1975). The approach considers the relative ability of a channel to transport sediment, measured by the tidal prism Ω and the total transport from adjacent shores into the inlet M_{tot} . The ratio Ω/M_{tot} is an index describing the type of sediment bypassing present at a particular inlet. For $\Omega/M_{tot} > 100$, inlet flow is large compared with the sediment load from littoral drift. and as a result the inlet remains fairly stable. For Ω/M_{tot} between 50 and 100, large offshore bars develop, but the bars are deep and do not interfere with navigation. For $\Omega/M_{tot} < 50$, large, shallow bars are common, and the inlet is unstable. These inlets are termed "bar bypassers." Three kinds of stability are noted: bypassing stability (ability to bypass littoral transport across the inlet), locational stability (rate of migration of the channel), and cross-sectional stability (maintenance of a cross-sectional area).

13. The two approaches discussed above attempt to relate the hydraulic characteristics of an inlet to the inlet's stability. Both approaches are primarily concerned with the ability of an inlet to remain open or changes in A_C . Neither approach attempts to quantify how inlet morphology (other than A_C) will change. Channel position and orientation have not been major stability criteria in past work. The O'Brien and Dean (1972) approach attempts to define the amount of sediment an inlet can absorb before the inlet becomes progressively more unstable. Bruun, Gerritsen, and Bhakta (1975) attempt to relate the flushing capacity of an inlet to the amount of littoral drift that must be bypassed. However, the types of instabilities that can be expected for given β and Ω/M_{tot} values are not known. It would be most beneficial to know in what fashion the inlet will respond to a decrease in its capacity to remove sediment deposited in its throat and channel areas.

PART III: PROCEDURE

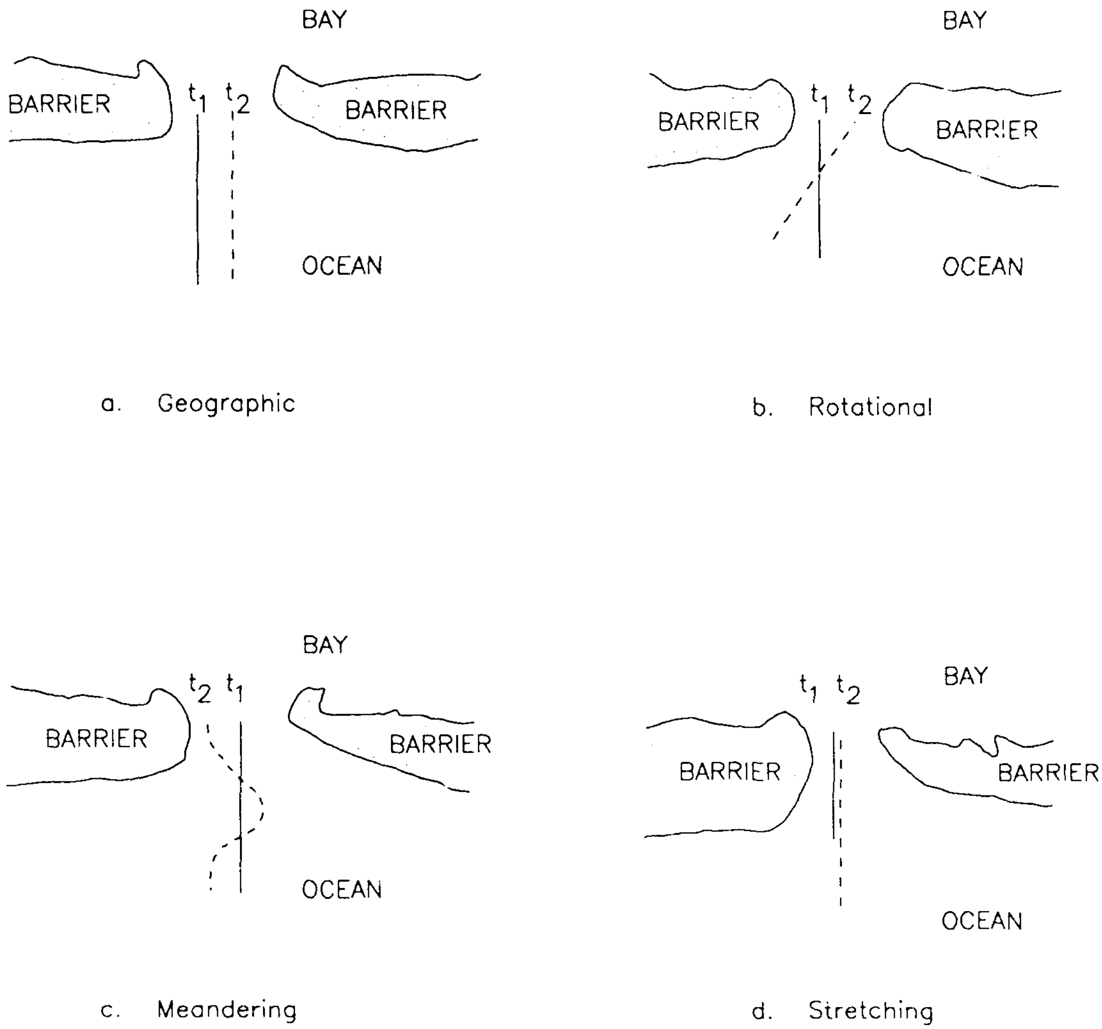
14. Consideration of the problem of stable versus unstable inlets suggests that an appropriate definition of a stable inlet is an inlet in which (a) depths and configuration do not vary much and do not establish a major trend and (b) change tends to create a self-restoring equilibrium. In engineering usage, however, these requirements are normally relaxed so that a stable inlet may change as long as it is a very slow process not requiring extensive dredging or stabilization measures. It is also reasonable to expect, in terms of the Corps mission, that to a large extent the use of an inlet determines the degree to which an inlet is termed stable or unstable.

15. Since the scope of this project is primarily limited to analysis of change in inlet systems from aerial photography, the types of instability considered must be restricted to changes in the inlet channel geographical location and horizontal topology. However, it is still pertinent to outline a series of instabilities that can be expected, including depth considerations.

16. The first type of instability may be termed purely geographic (Figure 1a): the inlet channel preserves its depth, geometry, and length but migrates substantially either consistently or about some mean location. A second type is rotational instability (Figure 1b). Again, all pertinent channel characteristics remain fixed, but the channel location pivots about one location. A third type of instability is meandering (Figure 1c), in which the mean channel and characteristics are position constant, but the channel becomes sinuous. A fourth type of instability is channel stretching (Figure 1d), in which the channel lengthens and other properties remain constant. It is readily seen that various combinations of these basic types of change in channel configurations can occur simultaneously. Added to these complex horizontal, topologic changes can be variations in depths of the channel and bar, inlet width, and area of the outer bar.

Hydraulic Variations

17. Two inlet characteristics that are easily measured from aerial photographs are minimum width W and length of the main channel L. In this



t_1 : Channel trace at time t_1

t_2 : Channel trace at a later time t_2

Figure 1. Types of channel instability

study, W and L will be termed hydraulic parameters because they have an inherent relationship to the hydraulic characteristics of the inlet as opposed to positional characteristics of the inlet.

Positional Variations

18. Although inlet stability is generally discussed in terms of shoaling of the entrance, it is important to consider geographic or positional shifts in the channels. It seems reasonable that shifts in channel location have concurrent changes in channel depth or width. However, even if the hydraulic characteristics do not change appreciably during channel migration, the shifts may still cause problems. First, channel migration creates significant difficulty in marking the channel for navigation. Second, channel migration may cause significant erosion of adjacent land. Third, the new orientation may be so aligned as to be unsafe for navigation under moderate and unfavorable wave conditions.

Formulation of Stability Indices

19. It is desirable to formulate a method for quantifying stability. The first problem encountered is a definition of what is to be measured. It was decided for this investigation to try to standardize the sections of the inlet that would be measured. The part of the inlet channel used for stability calculation is that segment between the minimum width cross section and the edge of the outer bar (Figure 2). A more detailed discussion of detection of this channel on aerial photographs is given later.

20. It is evident that, for an unstable inlet, the positions of the end points of the channel and the configuration of the channel between the end points will vary considerably. The method used to quantify this is as follows:

a. On the channel (between end points) at time t, points are located with coordinates (X_{it}, Y_{it}) appropriate to

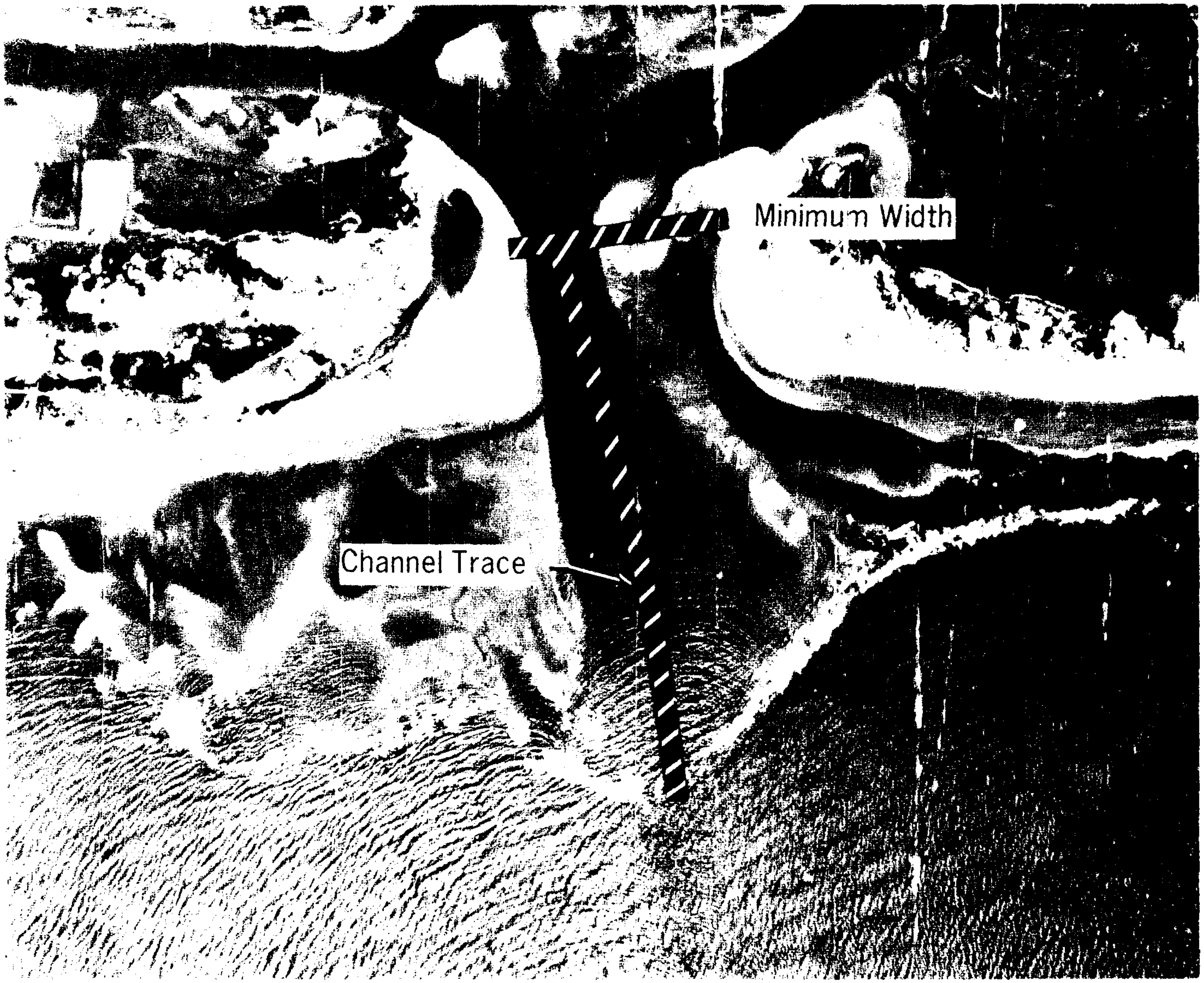


Figure 2. Example determination of inlet channel trace and minimum width

some geographical grid system, where i is a counter, increasing from 1 to N, and N is the number of points on the channel trace. The point with $i = 1$ is at the minimum width cross-section end point of the channel and the point with $i = N$ is located at the edge of the outer bar. The remaining $N - 2$ points are equally spaced along the arc length of the channel (of length L_t) at a distance $L_t/N - 1$ apart.

b. At some later time $t + \Delta t$, where Δt is the time increment, a similar set of N points are located equally spaced at distance $L_{t+\Delta t}/N - 1$.

c. The Euclidean distance (d_i) is then taken between equivalent points at different time levels

$$d_i = ((X_{it} - X_{it+\Delta t})^2 + (Y_{it} - Y_{it+\Delta t})^2)^{0.5}, \quad i = 1, N \tag{2}$$

A measure of change for the entire channel between time t and $t+\Delta t$ is then an N component vector

$$\underline{D}_{t,t+\Delta t} = (d_1, d_2, \ldots, d_N) \tag{3}$$

d. From $\underline{D}_{t,t+\Delta t}$, two scalar functions can be computed as follows:

$$\eta_{t,t+\Delta t} = \frac{(\underline{D}_{t,t+\Delta t})\ \underline{I}}{N} \tag{4}$$

$$\epsilon_{t,t+\Delta t}{}^2 = \frac{(\underline{D}_{t,t+\Delta t} - \eta_{t,t+\Delta t}\ \underline{I})^2}{N} \tag{5}$$

where N is the number of points on the channel trace and $\underline{I}$ is an N component unit vector. The variable $\eta_{t,t+\Delta t}$ is simply the mean change in position in the channel as a whole and ϵ is the standard deviation, describing how uniform (or nonuniform) the change has been over the length of channel.

21. The two indices, $\eta_{t,t+\Delta t}$[1] and $\epsilon_{t,t+\Delta t}$[1], can be used to summarize most of the geographical changes in the channel configuration. If there has

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[1] For notational simplicity, the subscript $t,t+\Delta t$ will be dropped.

been little change in channel position, η will tend to be near zero, and ϵ will be small. If, however, the channel has undergone a pure parallel shift, η will be large, and ϵ will be small. For changes in channel orientation that are in roughly the same channel location, η will be small, and ϵ will be large. For large values of both η and ϵ, a combination of shifts and change in orientation occurs. Figure 3 illustrates these changes. It should be noted that changes in length, with no other geographic change, produce intermediate values of η and ϵ.

Photogrammetric Considerations

22. Aerial photography was the data set used in this study because it was the only available data source with sufficient temporal coverage to address stability considerations. Even with aerial photography, many inlets have too few data for analysis. Three different aspects of data collection from photographic sources must be addressed: identification of the channel on the photograph, mapping of the channels onto a common grid system, and identification of possible sources of errors.

Identification of Channel and Other Parameters

23. Minimum inlet width is determined from the photography as the straight-line width from high-water mark to high-water mark that is minimum. Because inlet width fluctuates with tidal stage and wave height, high-water marks were chosen because they represent, on the average, the widest limits for the minimum width of the inlet throat. Figure 4 provides an example of minimum width identification on aerial photographs.

24. Determination of channel location on photographic images is somewhat more difficult. On photographs of water that is not too turbid, relative depths can be distinguished by tonal variations with the deepest

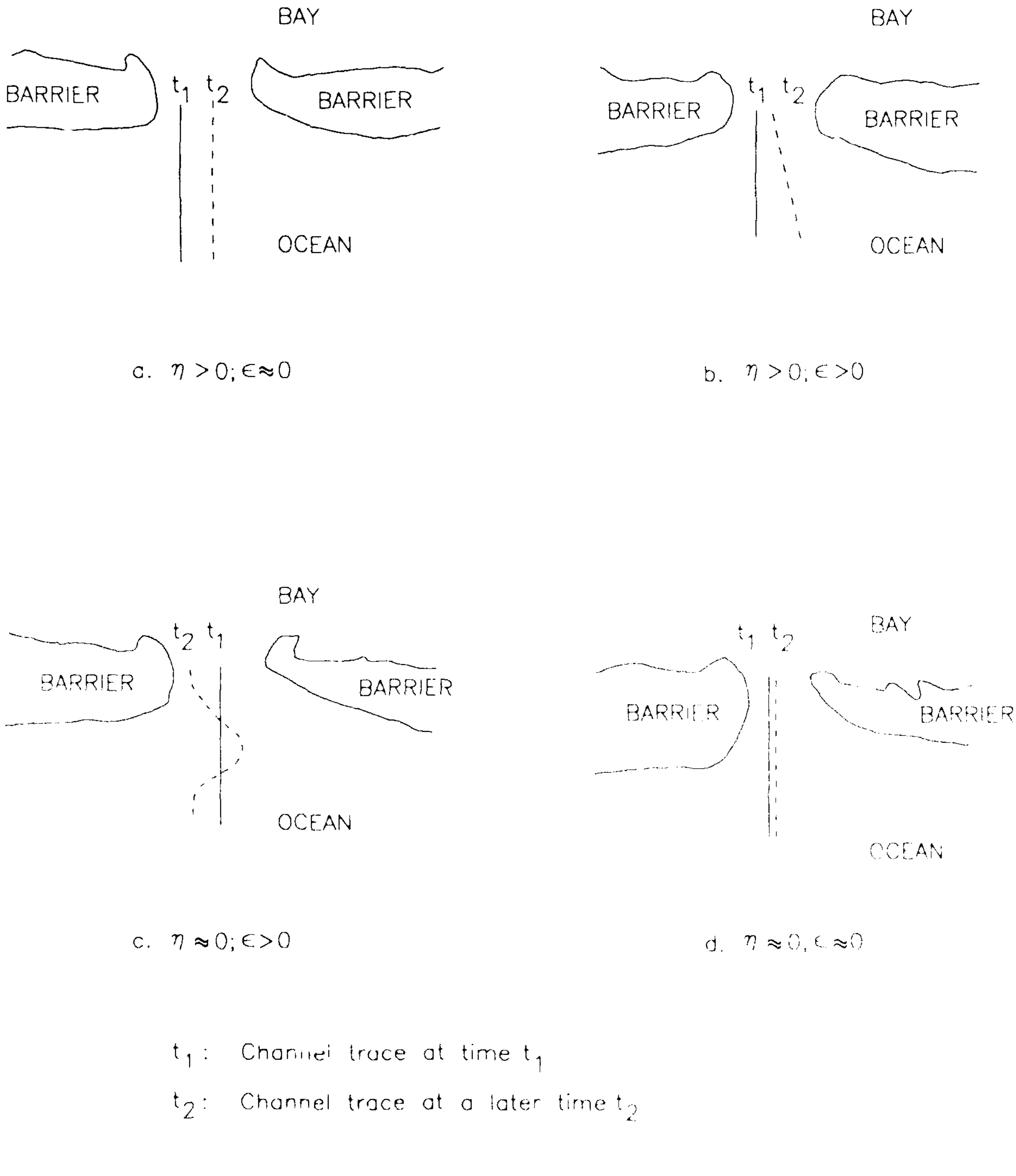

Figure 3. Examples of channel geographic instability

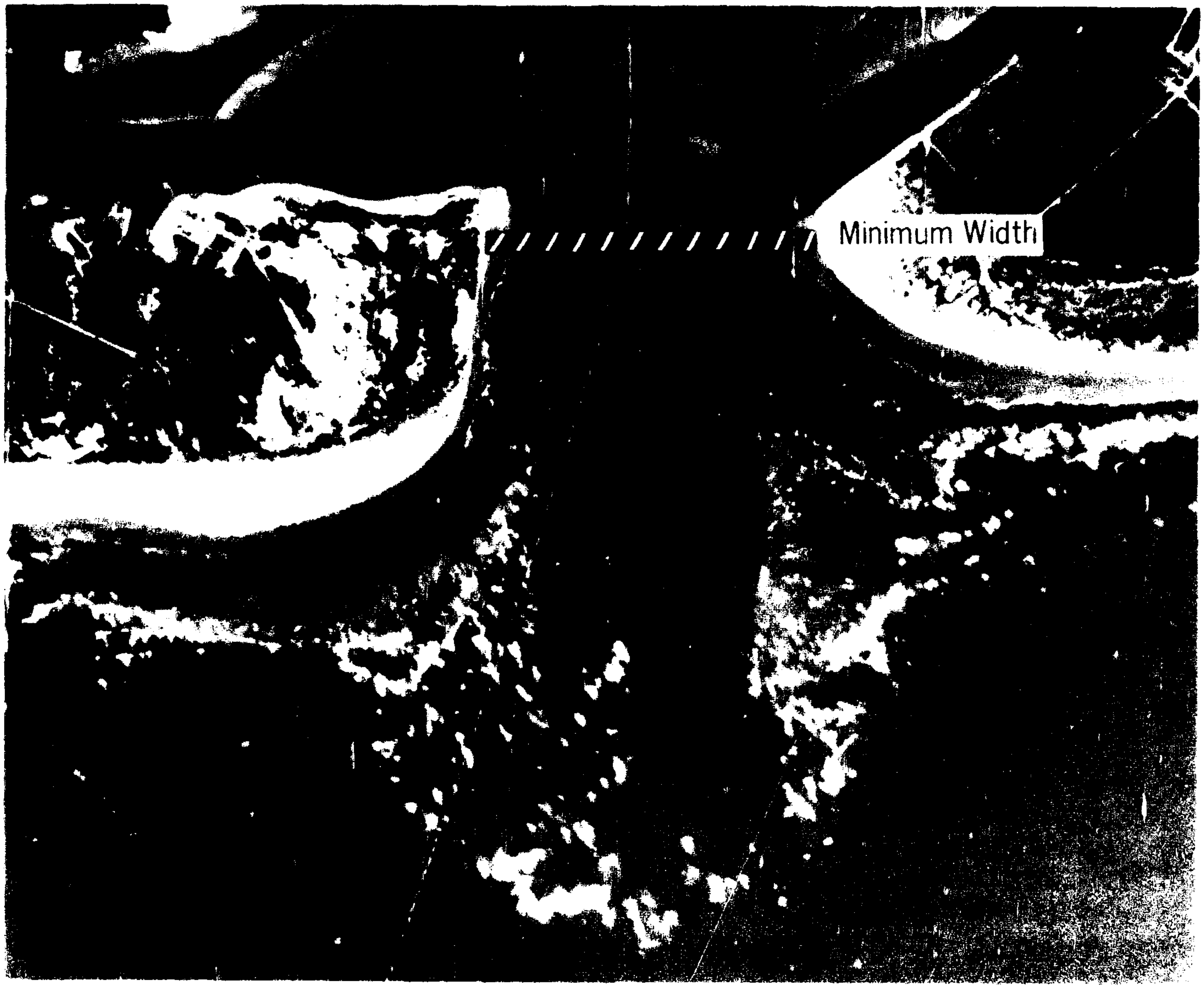

Figure 4. Example of minimum width determination

areas dark and the shoal areas light gray or nearly white. Further, waves tend to propagate straight-crested up the channel but show marked refraction over shoals. Thus, analyses of wave crests and wave breaking provide additional evidence for the location of channels. Using these indicators, the channel can be visually recognized and a center line estimated and drawn. An example of channel identification is given in Figure 5.

25. With the channel located, it is then necessary to determine its end points. The intersection of the channel center line with the minimum inlet width line provides one end point. The seaward end point is defined as the intersection of the channel center line with the crest of the outer bar. As in identification of the channel center line, analysis of shallow and deep areas from tonal contrasts and refraction patterns and breaker lines are used to determine the seaward end point (Figure 6).

26. Determination of the channel's seaward end point is the most difficult task of the identification and mapping process. Likewise, its determination can be subject to more error than that of the minimum width line or channel center line. Factors influencing these errors include:

a. The outer bar in the channel is normally broad crested, and as such there is some uncertainty in picking an end point location even if bathymetric charts, rather than photography, are used.

b. Where water depths are shallow and tonal variations are used to differentiate the bar crest, comparison of end points from different times can be influenced by variations in turbidity.

c. Use of refraction patterns and breaker lines to estimate the crest of the outer bar can lead to significant variation in end point location in photographs taken at different times because varying wave conditions will alter both patterns. However, most aerial photographs are taken in calm weather, which reduces the possible variation somewhat.

27. The three difficulties listed above were mitigated in the following ways. First, only photographs on which the channel and the bar crest were consistently definable were used in the analyses. Second, after all channels for an inlet were mapped, they were superimposed on one another, and the variation in the end point at the crest of the bars was reviewed. If one channel appeared anomalously long or short, the photograph was reanalyzed to see if the channel was indeed as previously defined. If the problem was one resulting from marginal quality photography, the photograph was excluded from the sample. Some random variability in channel length should be expected, but

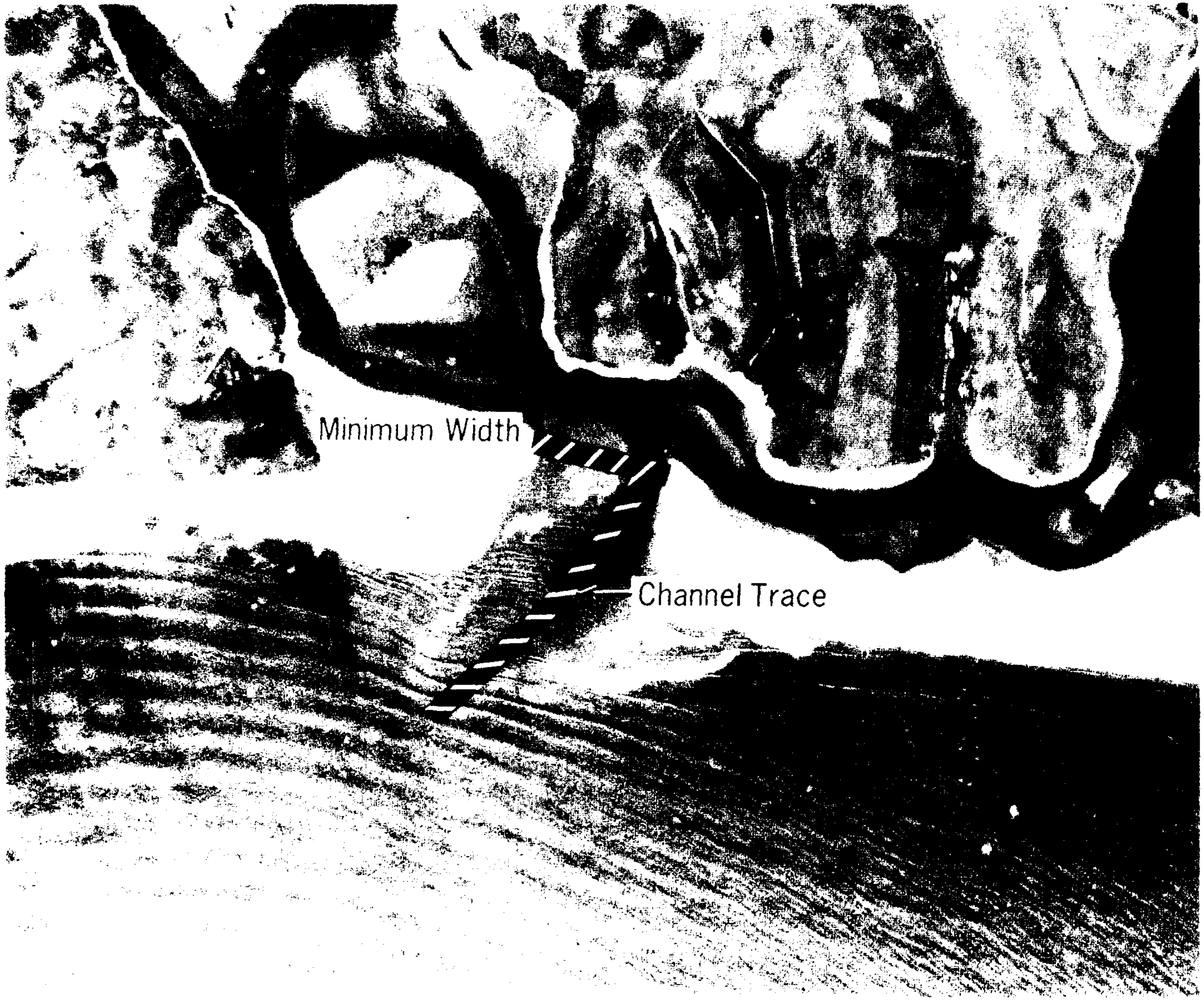

Figure 5. Example of inlet channel identification

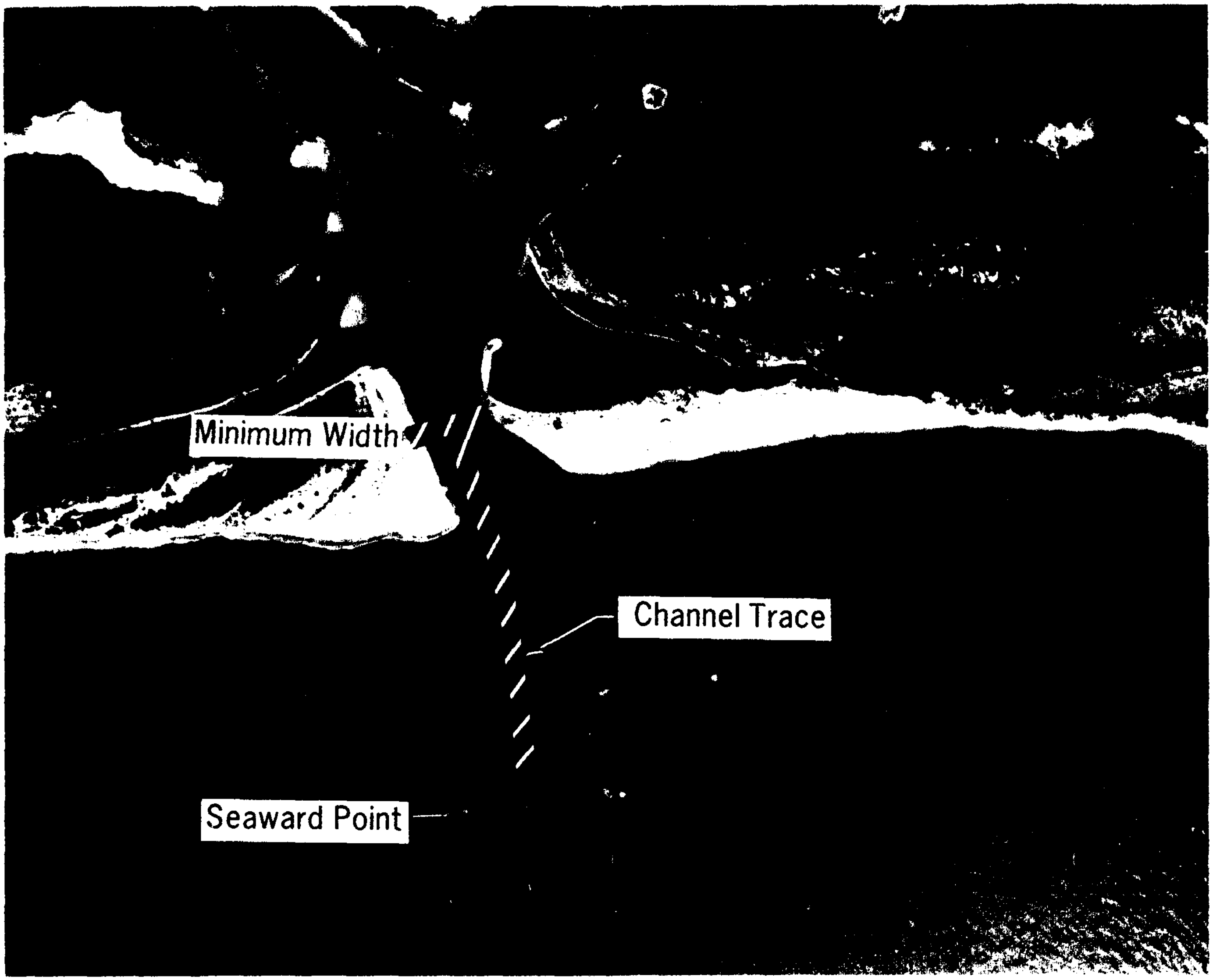

Figure 6. Example of determination of channel end points

care was taken to assure that a trend in length is real and not an artifact of photointerpretation.

Mapping

28. Photographs used for analysis of a particular inlet varied in scale and midpoint location. For use in the stability analysis, each channel was mapped onto a common geographical grid. Fortunately, inlet areas are relatively flat; as a result, problems involved with photographic tilt are small if measurements are taken near the center of the photograph. Photograph scales typically ranged from 1:4,800 to 1:24,000. Distances on the photograph can be measured to the nearest 0.01 in.[1]; hence, prototype values can vary by 25 to 50 ft[2]. This is well within the ability to define channels in the simple manner employed in this study. Hence, photogrammetric errors were considered unimportant compared with errors in interpretation and definition of inlet parameters.

29. For each of the selected inlets, the following procedure was used to map the channels:

- a. All photographs to be analyzed were surveyed and three or four control points common to all photographs were selected.
- b. On each photograph, the minimum inlet width was identified and measured. The channel line and end points were identified and traced onto a Mylar overlay along with the control points.
- c. Each Mylar overlay was overlain on a fixed grid, and the channel location and control points digitized by hand. Channel digitization allowed a variable distance between digitized locations, with the constraint being that the minimum number of digitized locations was sufficient to define the channel line. Both grid orientation and variable digitization were allowed because mapping was handled numerically.
- d. Digitized data were input to a computer program that mapped the channels onto a common grid, computed stability indices, and plotted the channels at a common scale.

The scale used as the final scale to which the data were transformed was arbitrarily selected as that of the earliest photograph. Since the comparisons to

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1 To convert inches to centimetres, multiply by 2.54.

2 To convert feet to metres, multiply by 0.3048.

be made are all relative comparisons, such a choice of scales is as reasonable as any other. A comparison of a numerically plotted channel with the original channel line is given in Figure 7.

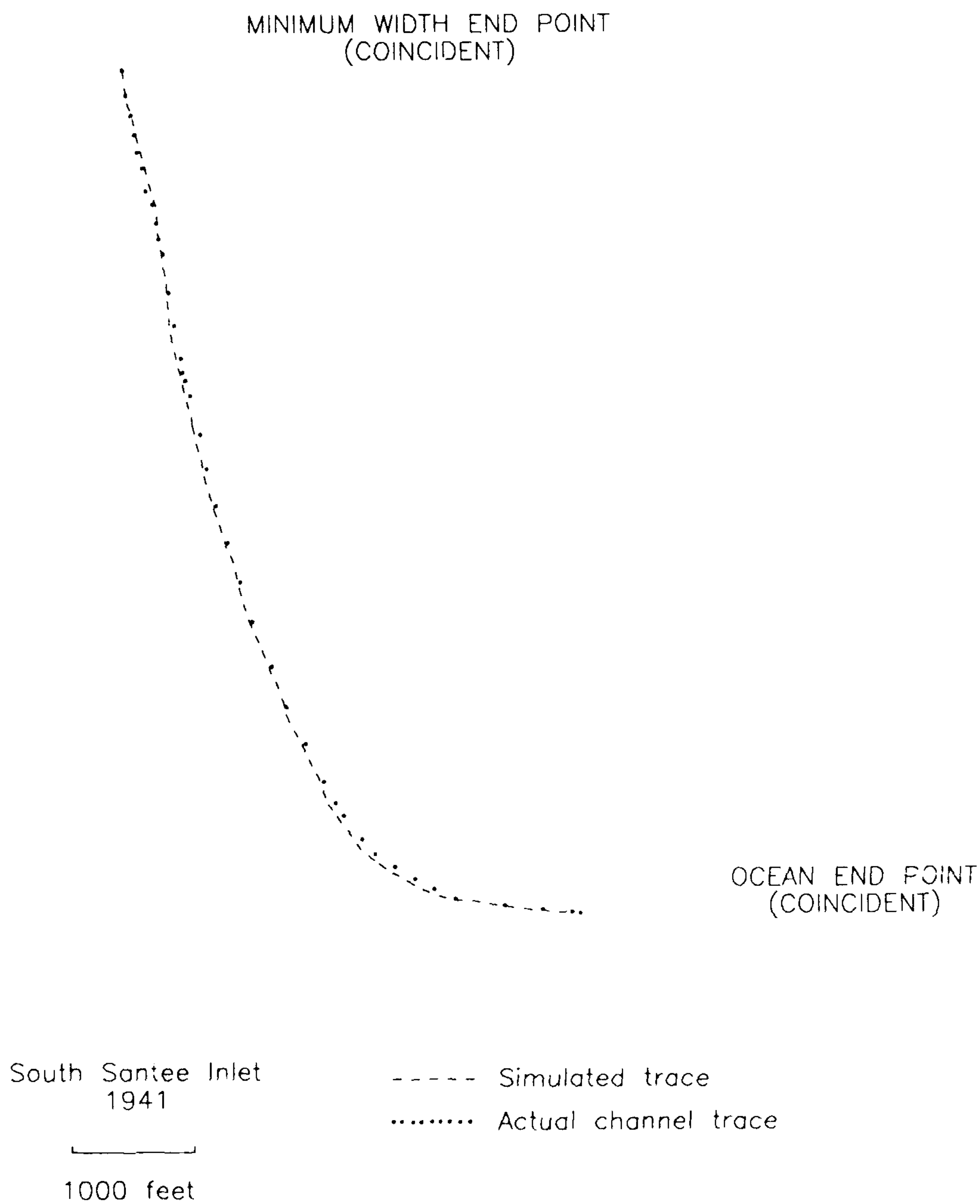

Figure 7. Comparison of numerically simulated trace and actual channel trace

PART IV: RECENT INLET VARIABILITY

Quantitative Results

30. Data used in this study are listed by inlet in Appendix B and displayed graphically in Appendix C. The data are arranged so that all information for one inlet is together. Appendix B lists stability indices for each inlet for each date evaluated. Included in Appendix C are: (a) a plot of temporal change in channel position (η) and orientation (ϵ) (relative to an initial condition), channel width and length, and (b) a plot with all channel traces superimposed. The position and orientation values for change from one date to a later date are plotted at the later date. In (b), the shoreline for the first photograph is given for orientation.

Discussion

31. Review of Appendices B and C indicates that few inlets show substantial stability over the 20- to 30-year period bracketed by this study. An attempt to discuss each inlet individually is unnecessary because the graphical portrayal of W, L, η^{*}[1], and ϵ in Appendix C suffices.

32. A summary of the time variance of the inlet properties is given in Table 2. The index ϵ is not characterized in Table 2. Review of the inlet plots indicated, to a large degree, all inlets exhibited the same behavior. The seaward end of the channel undergoes frequent movement or swing. Initially an effort was made to classify the change as either swing or oscillatory. Swing would imply movement of only the outer end of the channel with the throat remaining relatively fixed. Oscillatory would imply a change in orientation of the entire channel. Review of the inlets indicated that such a characterization was too hard to definitively apply and was dropped. Also included in Table 2 is a summary of the variability of movement of the inlet through near the minimum width cross section (column labeled throat). Since

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[1] For notational simplicity, the asterisk will be dropped.

Table 2

Recent History of Inlet Variability

Inlet Number	Inlet Name	W	L	η	Throat
1	Moriches	R[1]	T	T	T
2	Fire Island	R	SC	SC	R
3	Brigantine	T	T	T	LC
4	Corson	LC	LC	T	T
5	Townsend	R	SC	SC	R
6	Hereford	LC	SC	T	T
7	Gargathy	T	SC	T	T
8	Metomkin	T	T	R	R
9	Wachapreague	T	T	R	R
10	Oregon	SC	SC	LC	LC
11	Hatteras	T	T	T	T
12	Beaufort	T	SC	SC	SC
13	Bogue	LC	LC	LC	LC
14	New Topsail	T	LC	LC	LC
15	Rich	LC	LC	LC	LC
16	Carolina Beach	SC	T	T	T
17	Lockwoods Folly	SC	T	LC	LC
18	Shallotte	T	T	T	R
19	Tubbs	LC	T	T	T
20	Little River	T	LC	LC	T
21	Murrells	T	LC	LC	T
22	North	LC	T	T	T
23	South Santee	T	T	LC	LC
24	Price	SC	T	SC	T
25	Capers	T	SC	SC	R
26	Dewees	R	SC	SC	R
27	Lighthouse	LC	LC	T	R
28	Nassau-N	R	LC	T	T
29	Nassau-S	R	LC	LC	T
30	Ft. George	SC	SC	T	T
31	St. Augustine	LC	LC	LC	T
32	Matanzas	LC	LC	LC	R
33	Ponce De Leon	T	R	T	R

(Continued)

[1] R = random variation; SC = cyclic short period variation; LC = cyclic long period variation; T = trend variation.

Table 2 (Concluded)

Inlet Number	Inlet Name	W	L	η	Throat
34	Sebastian	T	SC	SC	R
35	Boca Raton	R	T	R	R
36	Hillsboro	T	T	T	R
37	Redfish	R	R	SC	R
38	Gasparilla	T	R	T	R
39	Stump	T	R	T	T
40	Midnight	LC	LC	LC	LC
41	Big Sarasota	T	LC	LC	R
42	Longboat	T	T	T	R
43	Pass A Grille-S	R	T	T	T
44	Pass A Grille-N	LC	LC	LC	T
45	Clearwater	T	SC	SC	R
46	San Luis	T	T	T	T
47	Bolinas	R	T	SC	R
48	Drakes	SC	SC	T	LC
49	Siuslaw	R	T	T	R
50	Siletz	R	LC	SC	R
51	Netarts	LC	LC	SC	T

this cross section is not constant in location, a line was drawn orthogonal to the main trend of the channel, somewhat seaward of the throat such that it crosses all channels.

33. The terminology used in Table 2 is as follows:

a. Random (R). Small variations in an index show no major trend.

b. Cyclic, short period (SC). The index varies in a cyclic manner with a period that is small compared with the period of record. In general, the amplitude is larger than for the R category and the variation is more consistent.

c. Cyclic, long period (LC). The index varies in an apparent cyclic manner with a period that is long compared with the period of record. The graph of the parameter appears quasi-parabolic. Rarely a shorter period cycle may be present as well.

d. Trend (T). The index establishes a marked trend which is more dominant than any smaller cyclic variation that may be superimposed.

Examples of inlets exhibiting this type of variability include Dewees (random width changes), Gargathy (length, short-period cycle), Bogue (long-period cycle in η), and Hatteras (trend in channel position at the inlet throat).

34. Approximately 60 percent of the inlets exhibit width variations that have a trend (40 percent) or an apparent long-period cycle (20 percent). In terms of channel length, the same proportion holds, but inlets with trends only slightly outnumber those with long-period cycles. For the geographic index η , about 40 percent of the inlets show a trend, 20 percent a long-period cycle, and 20 percent a short-period cycle. Very few inlets are characterized by a random type variability. For location of the channel in the throat, 40 percent of the inlets show a random type variability, 30 percent a trend, with most of the remainder showing a long-period cycle.

35. A result of this survey suggests that a large proportion of the inlets, ranging up to 60 percent, show either a marked trend or a discernible long-period cycle in one or more of their stability characteristics. Such trends or cycles may cause a variety of engineering problems in the inlet vicinity. If the inlet widens, it may be at the expense of adjacent shorelines that may experience accelerated erosion, whereas if the inlet narrows, shoaling and closure may be a problem. Likewise, the continuous shift in channel position may also result in shoreline erosion or navigation difficulties.

36. Short-period cycles may not be associated with shoreline erosion problems, but may be indicative of channels that are difficult to mark for navigation. Inlets showing random type variations may be close to stable. It should be noted that 30 to 40 percent of the inlets have one or the other of these two properties (random or short-term cycles), but that no inlet in the sample is completely stable. The closest in terms of the properties considered here is Redfish Pass in Florida.

37. Also of interest in addition to the simple summaries provided in Table 2 is the correlation between the time variant properties of the four indices. Interest is given to the frequency with which trend, as an example, in one index at an inlet corresponds to trend in another index. For all combinations of W , L , η , and throat , various combinations of the time variant properties (R , SC , LC , and T) are considered.

38. The relationships among time variation of the indices are presented in Table 3. For inlets showing a random variation in W , more show a trend in L . Those with a short-period cycle in W are mainly divided into a trend in L or a short-period cycle in L . Inlets with a long-period cycle in W show a great predominance to a similar type cycle in L . For trends in W , only slightly more inlets show trends in L than short-period cycles.

39. Table 3 suggests that those inlets showing trends in W have trends in the geomorphic stability index η . Those inlets with long-period cycles in W have long-period cycles in η . Trends in W more frequently are related to random type variations in the position of the inlet channel in the throat, and that random variation in width is likewise related more frequently to random variation in channel position. Long-period cycles in W are related more frequently to trends in the throat position.

40. Inlets with trends in L predominantly show trends in η . Those with long-period cycles in L have similar variations in η ; the correspondence for short-period cycles L and η holds as well. Inlets with trends in the location of channels in the throat are related primarily to trends in L and long-period cycles in L . A large proportion of inlets, however, with trends and cycles in L are related to random variations in channel position in the throat.

41. The relationship between position of the channel in the inlet throat and the index η is also shown in Table 3. Trends correspond to trends and long-period cycles to long-period cycles. Short-period cycles in η correspond most frequently to random variations in channel position in the throat.

42. Results from these analyses indicate a fairly high degree of correspondence among the time variant properties considered. However, the trends that are related are not necessarily in the same direction. For example, width may be increasing, whereas length decreases. The importance of the correspondences is that the change in the system is consistent. It should be noted, however, that few inlets show a consistent type of variation over all properties.

Table 3

Relationships Among Time Variant Characteristics

Channel Indices	R	SC	LC	T
W:L → ↓				
R	1	3	3	5
SC	0	3	0	3
LC	0	1	9	2
T	4	6	3	8
W:η → ↓				
R	1	6	1	4
SC	0	1	2	3
LC	0	1	7	4
T	2	4	4	11
W:Throat → ↓				
R	8	0	0	4
SC	0	0	3	3
LC	2	0	3	7
T	11	1	3	6
L:η → ↓				
R	0	1	0	4
SC	0	7	1	5
LC	0	2	11	2
T	3	2	2	11
L:Throat → ↓				
R	3	0	1	1
SC	6	1	2	4
LC	4	0	4	8
T	8	0	1	8
η:Throat → ↓				
R	3	0	0	0
SC	9	1	0	2
LC	2	0	7	5
T	7	0	2	13

PART V: DETERMINATION OF INLET STABILITY

43. It is clear from the previous section that most inlets exhibit some degree of instability either in position, orientation, or hydraulic characteristics (W , L). Since instability in inlets appears to cover a wide range of values, it is appropriate to consider stability in terms of a ranking of some measure of the magnitude of the instability. Two approaches are possible: relative values and absolute values. An assessment based on relative values consists of normalization of the stability indices so that the magnitude is shown relative to the inlet size. An assessment based on absolute considerations involves the magnitude of the change in stability indices irrespective of inlet size. The relative value assessment is considered first.

Relative Values of Inlet Stability

44. Consideration of relative values for stability indices is important because instability is then measured against the size of the inlet. For instance, a variation in channel width, over a period of record, by 1,000 ft is a small variation if the inlet is normally 10,000 ft wide. The same variation is highly significant, however, if the inlet is 300 ft wide. The following normalizations were formed, and the values are given in Table 4 for all inlets:

$\phi_1 = W_{max}/W_{min}$: where W_{max} is the maximum width recorded and W_{min} is the minimum

$\phi_2 = L_{max}/L_{min}$: where L_{max} is the maximum channel length recorded and L_{min} is the minimum

$\psi_1 = |\eta_{max} - \eta_{min}|/W_{min}$: where $\eta_{max} - \eta_{min}$ is the range in the stability index η

$\psi_2 = |\epsilon/\eta|_{max}$: where the ratio ϵ/η is computed for each time interval between photographs and the maximum taken

It is evident that ϕ_1 and ϕ_2 measure a relative range in the hydraulic character of the inlet. The parameter ψ_1 is a ratio of the range in geographic position of the channel to the minimum inlet width recorded.

Table 4

Relative Stability Parameters

Inlet Number	Inlet Name	ϕ_1	ϕ_2	ψ_1	ψ_2	Φ[1]	Ψ[2]
1	Moriches	3.5	4.1	12.5	2.5	3.7	5.6
2	Fire Island	1.6	1.9	1.8	7.1	1.7	3.6
3	Brigantine	3.7	1.2	1.9	1.8	2.1	1.8
4	Corson	6.0	1.5	6.6	3.6	3.0	4.9
5	Townsend	1.8	1.4	1.9	4.6	1.6	3.0
6	Hereford	5.4	1.3	2.5	29.1	2.6	8.5
7	Gargathy	3.6	1.6	10.4	1.7	2.4	4.2
8	Metomkin	1.4	1.7	0.3	22.5	1.5	2.6
9	Wachapreague	1.8	1.3	0.9	2.6	1.5	1.5
10	Oregon	4.1	2.4	2.3	3.8	3.1	3.0
11	Hatteras	3.1	2.1	1.8	29.8	2.6	7.3
12	Beaufort	2.0	1.6	0.5	4.6	1.8	1.5
13	Bogue	1.9	1.6	0.4	1.0	1.7	0.4
14	New Topsail	1.9	1.5	2.1	1.2	1.6	1.6
15	Rich	2.1	1.6	2.8	6.8	1.8	4.4
16	Carolina Beach	2.7	2.3	2.2	56.2	2.5	11.0
17	Lockwoods Folly	2.2	1.3	0.9	71.3	1.7	8.0
18	Shallotte	2.4	1.8	6.3	13.1	2.0	9.1
19	Tubbs	2.5	1.6	8.5	41.2	2.0	18.7
20	Little River	4.0	2.3	6.0	5.6	3.0	5.8
21	Murrells	2.7	2.0	2.3	1.3	2.3	1.7
22	North	1.9	1.3	1.1	4.2	1.4	2.1
23	South Santee	1.7	1.5	6.3	2.4	1.6	3.9
24	Price	2.2	1.6	3.7	11.2	1.9	6.4
25	Capers	1.5	1.7	1.9	1.9	1.6	1.9
26	Dewees	1.6	1.5	1.5	60.1	1.5	9.5
27	Lighthouse	1.9	1.2	0.9	5.0	1.5	2.1
28	Nassau-N	1.1	2.0	0.6	4.7	1.5	1.7
29	Nassau-S	1.1	1.2	0.4	1.1	1.1	0.4
30	Ft. George	1.2	1.8	3.6	7.2	2.7	5.1
31	St. Augustine	1.4	1.4	1.8	1.0	1.4	1.3

(Continued)

1 Combined relative hydraulic stability parameter ($\Phi = (\phi_1\phi_2)^{1/2}$).

2 Combined relative geographic stability parameter ($\Psi = (\psi_1\psi_2)^{1/2}$).

Table 4 (Concluded)

Inlet Number	Inlet Name	ϕ_1	ϕ_2	ψ_1	ψ_2	Φ	Ψ
32	Matanzas	1.6	1.5	1.1	1.2	1.5	1.1
33	Ponce De Leon	1.5	1.2	0.5	3.4	1.5	1.3
34	Sebastian	2.4	1.8	2.2	3.0	2.1	2.6
35	Boca Raton	1.4	1.6	0.8	6.7	1.5	2.3
36	Hillsboro	2.8	2.2	4.0	3.7	2.5	3.8
37	Redfish	1.4	1.3	0.9	5.8	1.3	2.3
38	Gasparilla	1.7	1.1	0.9	0.7	1.4	0.8
39	Stump	2.0	1.3	8.0	0.7	1.6	2.4
40	Midnight	3.2	1.3	10.4	1.9	2.0	4.4
41	Big Sarasota	1.2	1.3	0.4	1.4	1.2	0.7
42	Longboat	1.7	1.4	1.4	5.2	1.5	2.7
43	Pass A Grille-S	1.1	1.2	0.8	3.0	1.1	1.5
44	Pass A Grille-N	1.1	1.3	0.5	1.9	1.2	1.0
45	Clearwater	2.5	1.5	0.8	5.8	1.9	2.2
46	San Luis	1.7	1.3	0.7	2.9	1.5	1.4
47	Bolinas	1.8	1.8	2.9	1.5	1.8	2.1
48	Drakes	1.6	1.2	2.6	0.8	1.4	1.4
49	Siuslaw	1.3	3.0	1.0	2.1	2.0	1.4
50	Siletz	1.4	1.4	1.4	0.5	1.4	0.8
51	Netarts	1.5	1.1	0.8	1.3	1.3	1.1

The parameter ψ_2 is a ratio comparing the orientational change or swing of the channel with the overall change in channel position.

45. The parameter ϕ_1 ranges in value from about 1.1 to 6.0. As will be the case with ϕ_2 and L_{min}, when ϕ_1 is considered as a function of W_{min}, it is seen that the larger the inlet, the smaller ϕ_1 is likely to be. Thus, it is relatively easy for a small inlet (500 ft or so) to double its width; for a large inlet, 3,000 ft or greater, it is relatively harder. The large range in ϕ_1 should not be unexpected. An inlet can widen or narrow appreciably without a large increase or decrease in cross-sectional area. This narrowing may occur when a large shoal area emerges as a spit through the addition of only a few feet of sand. Likewise, the washover of a spit can increase the width with only a moderate erosion of sand.

46. The parameter ϕ_2 ranges only from 1.1 to 4.0, with most values between 1.0 and 2.0. This range is somewhat restricted compared with ϕ_1.

The length of a channel appears well related to the cross-sectional area of an inlet (Vincent and Corson 1980). Thus, for large changes in ϕ_2 to occur, fairly significant changes in the inlet throat must occur. Further, long channels tend to swing or bend and become hydraulically inefficient, resulting in a breakthrough and a shorter channel length.

Hydraulic stability

47. The parameters ϕ_1 and ϕ_2 are intended to measure the hydraulic stability of an inlet. Figure 8 provides a plot of ϕ_1 against ϕ_2. If the lower one-third of the range of each of ϕ_1 and ϕ_2 is considered stable, inlets with $\phi_1 < 2$ and $\phi_2 < 1.5$ can be termed hydraulically stable. Table 5 classifies each inlet by hydraulic stability; 22 are listed as hydraulically stable.

48. The remaining inlets can be divided into three additional categories. Inlets with $\phi_1 < 2$ and $\phi_2 > 1.5$ will be termed width-stable (implying length-unstable); 9 inlets are width-stable. Inlets with $\phi_1 > 2$ and $\phi_2 < 1.5$ are termed length-stable; 14 inlets fall into this category. Finally, there are inlets with $\phi_1 > 2$ and $\phi_2 > 1.5$. These 6 inlets are termed hydraulically unstable.

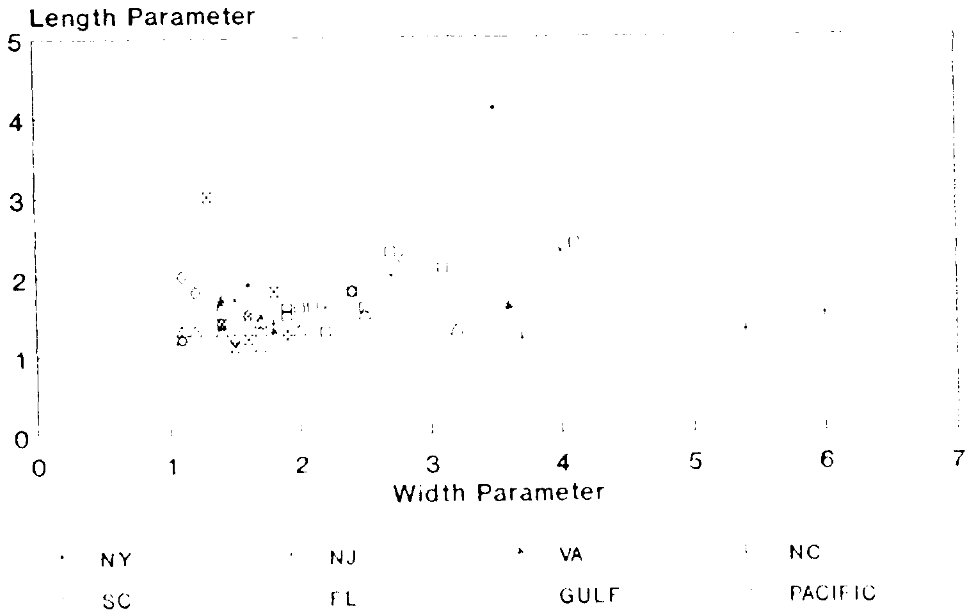

Figure 8. Plot of relative stability parameters ϕ_2 (length) versus ϕ_1 (width)

Table 5

Hydraulic Stability of Selected Inlets

Inlet Number	Inlet Name	ϕ_1 & ϕ_2 Stable	ϕ_1 Stable ϕ_2 Unstable	ϕ_1 Unstable ϕ_2 Stable	ϕ_1 & ϕ_2 Unstable
1	Moriches			x	
2	Fire Island		x		
3	Brigantine				x
4	Corson				x
5	Townsend	x			
6	Hereford				x
7	Gargathy			x	
8	Metomkin		x		
9	Wachapreague	x			
10	Oregon			x	
11	Hatteras			x	
12	Beaufort		x		
13	Bogue		x		
14	New Topsail	x			
15	Rich			x	
16	Carolina Beach			x	
17	Lockwoods Folly				x
18	Shallotte			x	
19	Tubbs			x	
20	Little River			x	
21	Murrells			x	
22	North	x			
23	South Santee	x			
24	Price			x	
25	Capers		x		
26	Dewees	x			
27	Lighthouse	x			
28	Nassau-N		x		
29	Nassau-S	x			
30	Ft. George			x	
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian			x	
35	Boca Raton		x		
36	Hillsboro			x	

(Continued)

Table 5 (Concluded)

Inlet Number	Inlet Name	ϕ_1 & ϕ_2 Stable	ϕ_1 Stable ϕ_2 Unstable	ϕ_1 Unstable ϕ_2 Stable	ϕ_1 & ϕ_2 Unstable
37	Redfish	x			
38	Gasparilla	x			
39	Stump	x			
40	Midnight				x
41	Big Sarasota	x			
42	Longboat	x			
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater				x
46	San Luis	x			
47	Bolinas		x		
48	Drakes	x			
49	Siuslaw		x		
50	Siletz	x			
51	Netarts	x			

49. Hydraulically stable inlets are those with relatively small variations in width and length. Width-stable inlets are those that exhibit principal hydraulic variations only in length. These variations may be caused by changes in channel depths in the inlet throat or by enlargement of the inlet bar by variations in longshore sediment transport. Length-stable inlets most likely are inlets with throat cross sections that remain fairly stable but which may have shallow shoal areas that vary in elevation above or below the mean water level with only moderate changes in cross-sectional area. Those inlets that are hydraulically unstable exhibit significant changes in all hydraulic characteristics.

50. The causes suggested above are not the only possible explanations for the observed variations. However, a detailed review of the hydraulic and morphologic characteristics of the inlets is not within the limited scope of this project.

<u>Positional stability</u>

51. The stability parameter ψ_1 measures the range in geographic position as a multiple of the minimum inlet width. The parameter can have a value less than 1 (ϕ_1 and ϕ_2 must be greater than 1 always). The range in

ψ_1 found in this analysis is from 0.3 to 12.5. Most inlets have ψ_1 values of 4 or less. If a value of 2.0 is taken as a stability limit (implying the inlet channel has not ranged more than two widths), it is seen that more than one-half of the inlets are positionally stable (Table 4).

52. The stability parameter ψ_2 measures the maximum ratio of the orientation swing to the overall positional shift of the channel. Large values imply a major swing in the outer part of the channel. The values in ψ_2 range from 0.5 to 60. Most inlets have values of ψ_2 less than 8.0. If a value of 2.0 is selected as the stability limit, slightly less than half the inlets will be orientationally stable. A value of 2.0 implies an orientation change approximately twice the movement of the general channel position.

53. Table 6 classifies each inlet according to geographic stability. The values of ψ_1 and ψ_2 are plotted against each other in Figure 9. There are eleven inlets with both ψ_1 and ψ_2 less than 2.0. These inlets will be termed geographically stable. Inlets with $\psi_1 > 2$ and $\psi_2 < 2$ will be termed orientation-stable; only seven inlets fall in this class. Nineteen inlets with $\psi_1 < 2$ and $\psi_2 > 2$ are termed position-stable. The remaining fourteen inlets are termed geographically unstable, with values of ψ_1 and $\psi_2 > 2$.

54. Geographically stable inlets require no explanation. Geographically unstable inlets are those showing significant change, or migration, in channel position and a change in channel orientation. Position-stable inlets are those in which the channel portion near the inlet throat does not move significantly while the outer portion of the channel may swing appreciably. Orientation-stable inlets are inlets in which the channel migrates substantially but change in orientation is not large compared with the shift in position.

Hydraulic stability - geographic stability variations

55. The two hydraulic stability parameters, ϕ_1 and ϕ_2 , and the geographic stability parameters, ψ_1 and ψ_2 , describe the relative variation of four principal aspects in which inlets can be expected to change in time. Previous sections of this report have explored the range in these basic types of inlet variation. It is pertinent to consider inlets in terms of the joint variation of hydraulic and geographic parameters. This is accomplished by examining the four combinations (ϕ_1,ψ_1), (ϕ_1,ψ_2), (ϕ_2,ψ_1), and (ϕ_2,ψ_2).

Table 6

Geographic Stability of Selected Inlets

Inlet Number	Inlet Name	ψ_1 & ψ_2 Stable	ψ_1 Stable ψ_2 Unstable	ψ_1 Unstable ψ_2 Stable	ψ_1 & ψ_2 Unstable
1	Moriches				x
2	Fire Island		x		
3	Brigantine	x			
4	Corson				x
5	Townsend		x		
6	Hereford				x
7	Gargathy			x	
8	Metomkin		x		
9	Wachapreague		x		
10	Oregon				x
11	Hatteras		x		
12	Beaufort		x		
13	Bogue	x			
14	New Topsail			x	
15	Rich				x
16	Carolina Beach				x
17	Lockwoods Folly		x		
18	Shallotte				x
19	Tubbs				x
20	Little River				x
21	Murrells			x	
22	North		x		
23	South Santee				x
24	Price				x
25	Capers	x			
26	Dewees		x		
27	Lighthouse		x		
28	Nassau-N		x		
29	Nassau-S	x			
30	Ft. George				x
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon		x		
34	Sebastian				x
35	Boca Raton		x		
36	Hillsboro				x

(Continued)

Table 6 (Concluded)

Inlet Number	Inlet Name	ψ_1 & ψ_2 Stable	ψ_1 Stable ψ_2 Unstable	ψ_1 Unstable ψ_2 Stable	ψ_1 & ψ_2 Unstable
37	Redfish		x		
38	Gasparilla	x			
39	Stump			x	
40	Midnight			x	
41	Big Sarasota	x			
42	Longboat		x		
43	Pass A Grille-S		x		
44	Pass A Grille-N	x			
45	Clearwater		x		
46	San Luis		x		
47	Bolinas			x	
48	Drakes			x	
49	Siuslaw		x		
50	Siletz	x			
51	Netarts	x			

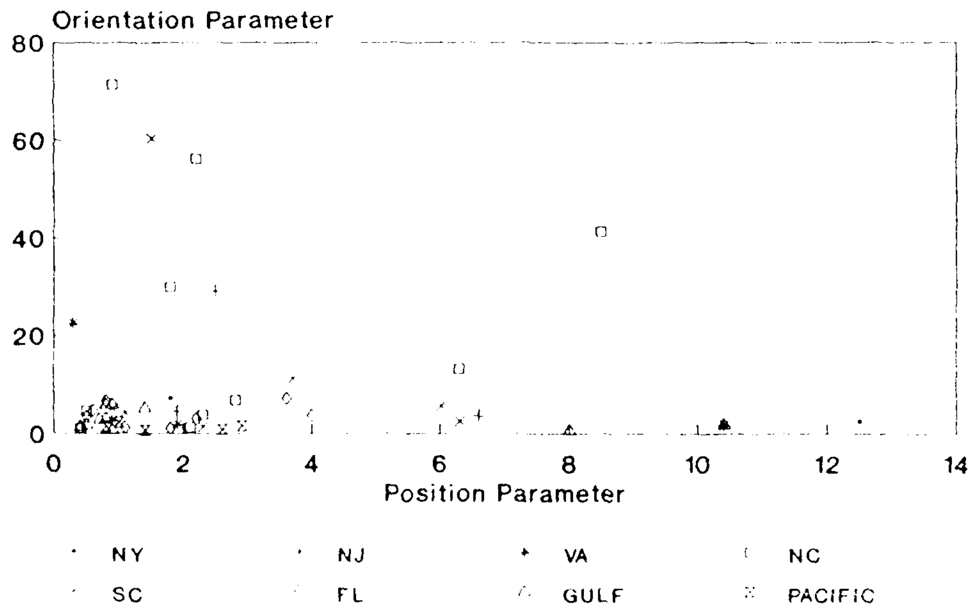

Figure 9. Plot of relative stability parameters ψ_2 (orientation) versus ψ_1 (position)

56. In Figure 10, ϕ_1 and ψ_1 are plotted. For convenience, the stability limits previously assumed for ϕ_1 and ψ_1 (2.0 for each) are maintained. Twenty-six inlets can be classified as ϕ_1 - ψ_1 stable (Table 7). Only five inlets are ψ_1-stable/ϕ_1-unstable, that is with $\psi_1 < 2$ and $\phi_1 > 2$. Four inlets are ϕ_1-stable/ψ_1-unstable and sixteen inlets are ϕ_1-ψ_1-unstable with both ψ_1 and ϕ_1 greater than 2. Inlets that are ψ_1-stable/ϕ_1-unstable must not move much geographically but do vary considerably in width. Inlets that are ϕ_1-stable/ψ_1-unstable exhibit a large range in geographic position, but remain relatively stable width-wise.

57. Assuming the stability limits previously used for ϕ_2 and ψ_1 (1.5 and 2.0, respectively), Figure 11 can be used to examine the variation between ϕ_2 and ψ_1. The number of inlets considered stable for both ϕ_2 and ψ_1 is 21 (Table 8). Nine inlets are classified as ψ_1-stable/ϕ_2-unstable; seven are ϕ_2-stable/ψ_1-unstable. The remaining fourteen inlets are ϕ_2-ψ_1-unstable. Both ϕ_2-ψ_1-stable and ϕ_2-ψ_1-unstable are self-explanatory. Inlets that are ϕ_2-stable/ψ_1-unstable are characterized by a large range in position and minor changes in length. Inlets labeled ψ_1-stable/ϕ_2-unstable exhibit large variations in channel length and minimal changes in position.

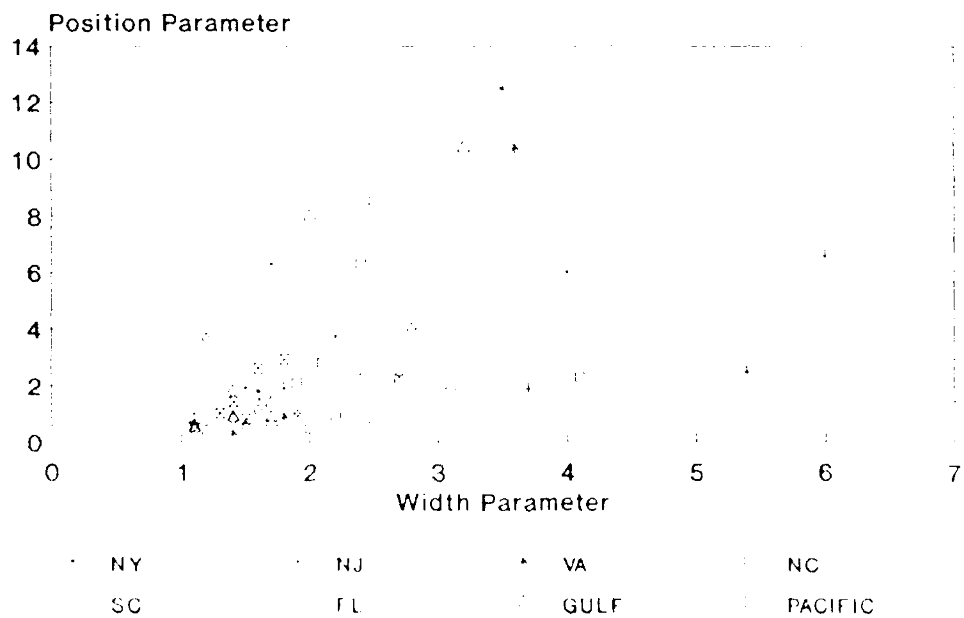

Figure 10. Plot of relative stability parameters ψ_1 (position) versus ϕ_1 (width)

Table 7

Combined Variation of Stability Parameters ϕ_1 and ψ_1

Inlet Number	Inlet Name	ϕ_1 & ψ_1 Stable	ϕ_1 Stable ψ_1 Unstable	ψ_1 Unstable ϕ_1 Stable	ϕ_1 & ψ_1 Unstable
1	Moriches				x
2	Fire Island	x			
3	Brigantine			x	
4	Corson				x
5	Townsend	x			
6	Hereford				x
7	Gargathy				x
8	Metomkin	x			
9	Wachapreague	x			
10	Oregon				x
11	Hatteras			x	
12	Beaufort	x			
13	Bogue	x			
14	New Topsail		x		
15	Rich				x
16	Carolina Beach				x
17	Lockwoods Folly			x	
18	Shallotte				x
19	Tubbs				x
20	Little River				x
21	Murrells				x
22	North	x			
23	South Santee		x		
24	Price				x
25	Capers	x			
26	Dewees	x			
27	Lighthouse	x			
28	Nassau-N	x			
29	Nassau-S	x			
30	Ft. George				x
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian				x
35	Boca Raton	x			
36	Hillsboro				x

(Continued)

Table 7 (Concluded)

Inlet Number	Inlet Name	ϕ_1 & ψ_1 Stable	ϕ_1 Stable ψ_1 Unstable	ϕ_1 Unstable ψ_1 Stable	ϕ_1 & ψ_1 Unstable
37	Redfish	x			
38	Gasparilla	x			
39	Stump		x		
40	Midnight				x
41	Big Sarasota	x			
42	Longboat	x			
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater			x	
46	San Luis	x			
47	Bolinas		x		
48	Drakes		x		
49	Siuslaw	x			
50	Siletz	x			
51	Netarts	x			

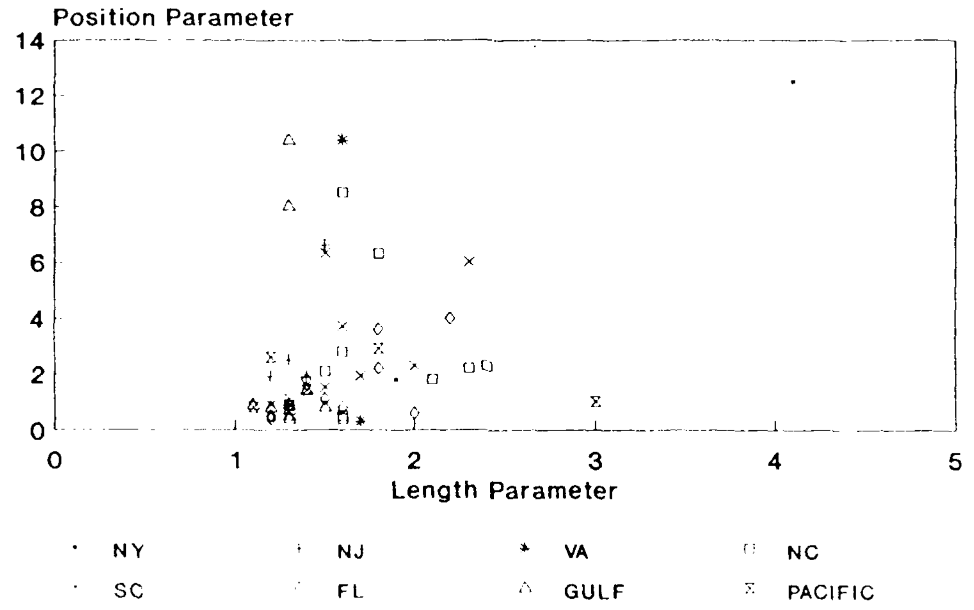

Figure 11. Plot of relative stability parameters ψ_1 (position) versus ϕ_2 (length)

Table 8

Combined Variation of Stability Parameters ϕ_2 and ψ_1

Inlet Number	Inlet Name	ϕ_2 & ψ_1 Stable	ϕ_2 Stable ψ_1 Unstable	ϕ_2 Unstable ψ_1 Stable	ϕ_2 & ψ_1 Unstable
1	Moriches				x
2	Fire Island			x	
3	Brigantine	x			
4	Corson		x		
5	Townsend	x			
6	Hereford		x		
7	Gargathy				x
8	Metomkin			x	
9	Wachapreague	x			
10	Oregon				x
11	Hatteras			x	
12	Beaufort			x	
13	Bogue			x	
14	New Topsail		x		
15	Rich				x
16	Carolina Beach				x
17	Lockwoods Folly	x			
18	Shallotte				x
19	Tubbs				x
20	Little River				x
21	Murrells				x
22	North	x			
23	South Santee		x		
24	Price				x
25	Capers			x	
26	Dewees	x			
27	Lighthouse	x			
28	Nassau-N			x	
29	Nassau-S	x			
30	Ft. George				x
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian				x
35	Boca Raton			x	
36	Hillsboro				x

(Continued)

Table 8 (Concluded)

Inlet Number	Inlet Name	ϕ_2 & ψ_1 Stable	ϕ_2 Stable ψ_1 Unstable	ϕ_2 Unstable ψ_1 Stable	ϕ_2 & ψ_1 Unstable
37	Redfish	x			
38	Gasparilla	x			
39	Stump		x		
40	Midnight		x		
41	Big Sarasota	x			
42	Longboat	x			
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater	x			
46	San Luis	x			
47	Bolinas				x
48	Drakes		x		
49	Siuslaw			x	
50	Siletz	x			
51	Netarts	x			

58. Figure 12 provides a cross plot of ϕ_1 and ψ_2. Using the same stability limits ($\phi_1 < 2$, $\psi_2 > 2$), fourteen inlets are determined to be ϕ_1-ψ_2-stable (Table 9). Four inlets are ψ_2-stable/ϕ_1-unstable, seventeen are ϕ_1-stable/ψ_2-unstable, and sixteen are ϕ_1-ψ_2-unstable. Inlets categorized as ϕ_1-stable/ψ_2-unstable have stable widths but experience large swings of the outer part of the channel. Inlets that are ψ_2-stable/ϕ_1-unstable have large variations in width but do not undergo relatively large changes in orientation.

59. The plot of ϕ_2 against ψ_2 is given in Figure 13. Using limits of 1.5 for ϕ_2 and 2.0 for ψ_2, thirteen inlets are ϕ_2-ψ_2-stable (Table 10). Five inlets are ψ_2-stable/ϕ_2-unstable, fifteen are ϕ_2-stable/ψ_2-unstable, and eighteen are ϕ_2-ψ_2-unstable. Inlets that are ψ_2-stable/ϕ_2-unstable have relatively large changes in length without large changes in orientation. Inlets that are ϕ_2-stable/ψ_2-unstable change orientation, but channel lengths do not vary excessively.

60. The previous discussion addresses the variability of inlet geographic or positional characteristics in relation to the variability of the hydraulic parameters. An inlet can fall into any of four "stability" classes

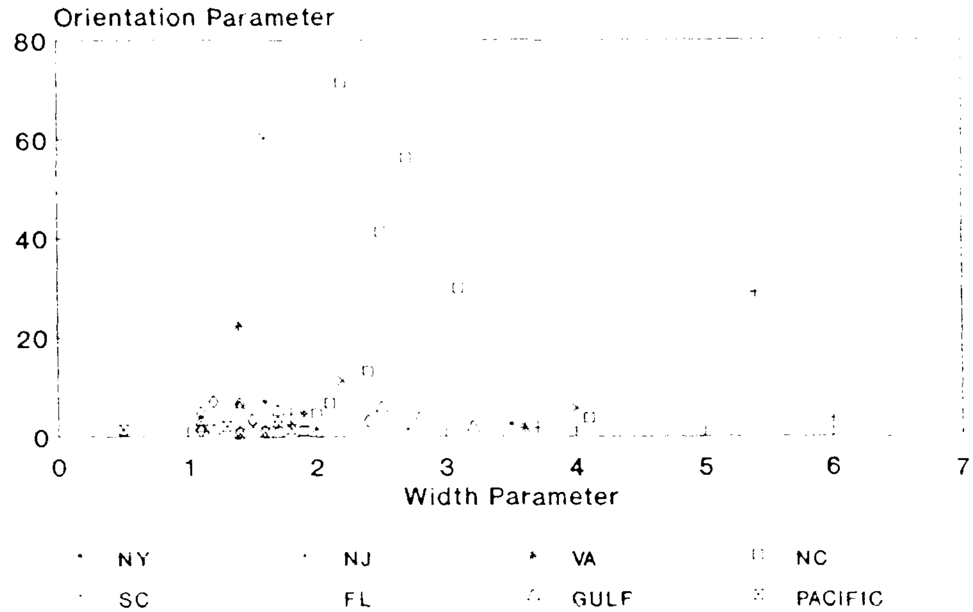

Figure 12. Plot of relative stability parameters ψ_2 (orientation) versus ϕ_1 (width)

Table 9

Combined Variation of Stability Parameters ϕ_1 and ψ_2

Inlet Number	Inlet Name	ϕ_1 & ψ_2 Stable	ϕ_1 Stable ψ_2 Unstable	ϕ_1 Unstable ψ_2 Stable	ϕ_1 & ψ_2 Unstable
1	Moriches				x
2	Fire Island		x		
3	Brigantine			x	
4	Corson				x
5	Townsend		x		
6	Hereford				x
7	Gargathy			x	
8	Metomkin		x		
9	Wachapreague		x		
10	Oregon				x
11	Hatteras				x
12	Beaufort		x		
13	Bogue	x			
14	New Topsail	x			
15	Rich				x

(Continued)

Table 9 (Concluded)

Inlet Number	Inlet Name	ϕ_1 & ψ_2 Stable	ϕ_1 Stable ψ_2 Unstable	ϕ_1 Unstable ψ_2 Stable	ϕ_1 & ψ_2 Unstable
16	Carolina Beach				x
17	Lockwoods Folly				x
18	Shallotte				x
19	Tubbs				x
20	Little River				x
21	Murrells			x	
22	North		x		
23	South Santee		x		
24	Price				x
25	Capers	x			
26	Dewees		x		
27	Lighthouse		x		
28	Nassau-N		x		
29	Nassau-S	x			
30	Ft. George				x
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon		x		
34	Sebastian				x
35	Boca Raton		x		
36	Hillsboro				x
37	Redfish		x		
38	Gasparilla	x			
39	Stump	x			
40	Midnight			x	
41	Big Sarasota	x			
42	Longboat		x		
43	Pass A Grille-S		x		
44	Pass A Grille-N	x			
45	Clearwater				x
46	San Luis		x		
47	Bolinas	x			
48	Drakes	x			
49	Siuslaw		x		
50	Siletz	x			
51	Netarts	x			

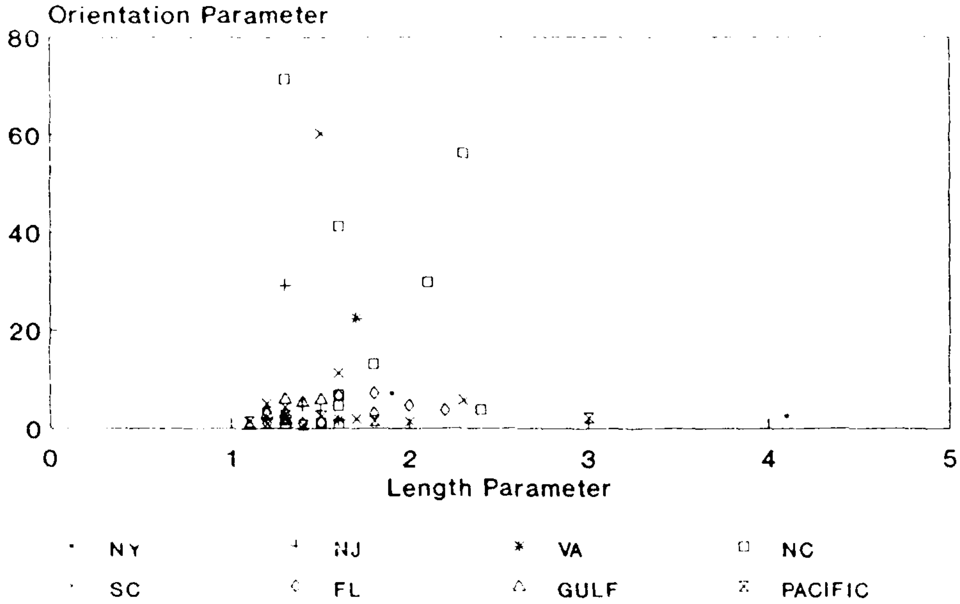

Figure 13. Plot of relative stability parameters ψ_2 (orientation) versus ϕ_2 (length)

Table 10

Combined Variation of Stability Parameters ϕ_2 and ψ_2

Inlet Number	Inlet Name	ϕ_2 & ψ_2 Stable	ϕ_2 Stable ψ_2 Unstable	ϕ_2 Unstable ψ_2 Stable	ϕ_2 & ψ_2 Unstable
1	Moriches				x
2	Fire Island				x
3	Brigantine	x			
4	Corson		x		
5	Townsend		x		
6	Hereford		x		
7	Gargathy			x	
8	Metomkin				x
9	Wachapreague		x		
10	Oregon				x
11	Hatteras				x
12	Beaufort				x
13	Bogue			x	
14	New Topsail	x			
15	Rich				x

(Continued)

Table 10 (Concluded)

Inlet Number	Inlet Name	ϕ_2 & ψ_2 Stable	ϕ_2 Stable ψ_2 Unstable	ϕ_2 Unstable ψ_2 Stable	ϕ_2 & ψ_2 Unstable
16	Carolina Beach				x
17	Lockwoods Folly		x		
18	Shallotte				x
19	Tubbs				x
20	Little River				x
21	Murrells			x	
22	North		x		
23	South Santee		x		
24	Price				x
25	Capers			x	
26	Dewees		x		
27	Lighthouse		x		
28	Nassau-N				x
29	Nassau-S	x			
30	Ft. George				x
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon		x		
34	Sebastian				x
35	Boca Raton				x
36	Hillsboro				x
37	Redfish		x		
38	Gasparilla	x			
39	Stump	x			
40	Midnight	x			
41	Big Sarasota	x			
42	Longboat		x		
43	Pass A Grille-S		x		
44	Pass A Grille-N	x			
45	Clearwater		x		
46	San Luis		x		
47	Bolinas			x	
48	Drakes	x			
49	Siuslaw				x
50	Siletz	x			
51	Netarts	x			

for each of four pairs of ϕ_i - ψ_i combinations. Table 11 summarizes the number of inlets in each of the 16 categories. It is desirable, however, to simplify this categorization by devising a single parameter to reflect hydraulic stability and another single parameter to indicate positional stability. The combined hydraulic stability parameter Φ is defined as

$$\Phi = (\phi_1\phi_2)^{1/2} \tag{7}$$

and the combined geographic or positional stability parameter Ψ is defined as

$$\Psi = (\psi_1\psi_2)^{1/2} \tag{8}$$

The parameter Φ can range upward from 1.0. The parameter Ψ can range upward from 0.

Table 11

Summary of Relative Hydraulic and Geographic Stability Parameters

Geographic Parameters	Hydraulic Parameters ϕ_1 Stable	ϕ_1 Unstable	ϕ_2 Stable	ϕ_2 Unstable
ψ_1 Stable	26	5	21	9
ψ_1 Unstable	4	16	7	14
ψ_2 Stable	14	4	13	5
ψ_2 Unstable	17	16	15	18

61. If the limits used for each parameter in the previous analyses are used to estimate stable limits for Φ and Ψ , stability values are

$$\Phi = 1.7$$

and

$$\Psi = 2.0$$

In Figure 14, Φ is plotted against Ψ . Table 12 indicates that seventeen inlets can be considered stable ($\Phi < 1.7$, $\Psi < 2.0$). Twelve inlets are hydraulically stable (but geographically unstable), and four are only geographically stable. The remaining eighteen inlets are classified as unstable ($\Phi > 1.7$, $\Psi > 2.0$).

Discussion

62. The stability, or instability, of inlets investigated as part of this study has been examined in relative terms. Stability indices defined in Part III have been transformed to normalize the raw data by parameters characteristic of inlet size. Thus, the absolute magnitude of variation is not as important as its relative magnitude in comparison to inlet size.

63. For each parameter, the range in relative magnitude has been considered, and a value approximately one-third of the more densely sampled part of the range was selected as a limit for stability. It should be emphasized

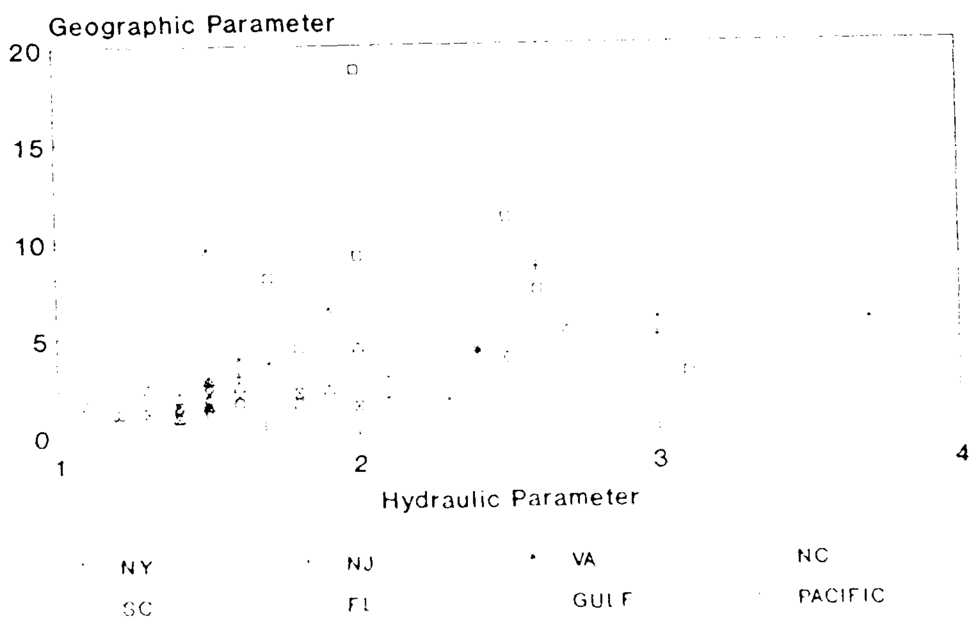

Figure 14. Plot of relative stability parameters Ψ (geographic) versus Φ (hydraulic)

Table 12

Combined Variation of Stability Parameters Φ and Ψ

Inlet Number	Inlet Name	Φ & Ψ Stable	Φ Stable Ψ Unstable	Φ Unstable Ψ Stable	Φ & Ψ Unstable
1	Moriches				x
2	Fire Island		x		
3	Brigantine			x	
4	Corson				x
5	Townsend		x		
6	Hereford				x
7	Gargathy				x
8	Metomkin		x		
9	Wachapreague	x			
10	Oregon				x
11	Hatteras				x
12	Beaufort			x	
13	Bogue	x			
14	New Topsail	x			
15	Rich				x
16	Carolina Beach				x
17	Lockwoods Folly		x		
18	Shallotte				x
19	Tubbs				x
20	Little River				x
21	Murrells			x	
22	North		x		
23	South Santee		x		
24	Price				x
25	Capers	x			
26	Dewees		x		
27	Lighthouse		x		
28	Nassau-N	x			
29	Nassau-S	x			
30	Ft. George				x
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian				x
35	Boca Raton		x		
36	Hillsboro				x

(Continued)

Table 12 (Concluded)

Inlet Number	Inlet Name	Φ & Ψ Stable	Φ Stable Ψ Unstable	Φ Unstable Ψ Stable	Φ & Ψ Unstable
37	Redfish		x		
38	Gasparilla	x			
39	Stump		x		
40	Midnight				x
41	Big Sarasota	x			
42	Longboat		x		
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater				x
46	San Luis	x			
47	Bolinas				x
48	Drakes	x			
49	Siuslaw			x	
50	Siletz	x			
51	Netarts	x			

that these are arbitrary assignments. However, neither stable nor unstable can have a true mathematical or distributional value because the terms are purely relative descriptions. The importance of the derived parameters is that they provide a quantitative measurement and ranking of inlet variation and may be used to relate the variational aspects of inlets to morphologic and hydrodynamic characterizations to better predict the behavior of such systems.

64. The analyses presented here attempt to categorize the variation of the inlets studied into four principal forms of variation. Two of these are considered properties descriptive of variation of hydraulic aspects of inlets; the remaining two describe positional and orientation changes in the inlet which are termed geographical. A final analysis summarizes the variation in four parameters by defining two simple parameters indicative of hydraulic and geographical stability. A summary by inlet of the ϕ_1, ϕ_2, ψ_1, ψ_2, Φ, and Ψ variational characteristics is given in Table 13.

Table 13

Relative Stability of Selected Inlets

Inlet Number	Inlet Name	ϕ_1	ϕ_2	ψ_1	ψ_2	Φ	Ψ
1	Moriches	1[1]	1	1	1	1	1
2	Fire Island	0	1	0	1	1	0
3	Brigantine	1	0	0	0	1	0
4	Corson	1	0	1	1	1	1
5	Townsend	0	0	0	1	0	1
6	Hereford	1	0	1	1	1	1
7	Gargathy	1	1	1	0	1	1
8	Metomkin	0	1	0	1	0	1
9	Wachapreague	0	0	0	1	0	0
10	Oregon	1	1	1	1	1	1
11	Hatteras	1	1	0	1	1	1
12	Beaufort	0	1	0	1	1	0
13	Bogue	0	1	0	0	0	0
14	New Topsail	0	0	1	0	0	0
15	Rich	1	1	1	1	1	1
16	Carolina Beach	1	1	1	1	1	1
17	Lockwoods Folly	1	0	0	1	0	1
18	Shallotte	1	1	1	1	1	1
19	Tubbs	1	1	1	1	1	1
20	Little River	1	1	1	1	1	1
21	Murrells	1	1	1	0	1	0
22	North	0	0	0	1	0	1
23	South Santee	0	0	1	1	0	1
24	Price	1	1	1	1	1	1
25	Capers	0	1	0	0	0	0
26	Dewees	0	0	0	1	0	1
27	Lighthouse	0	0	0	1	0	1
28	Nassau-N	0	1	0	1	0	0
29	Nassau-S	0	0	0	0	0	0
30	Ft. George	1	1	1	1	1	1
31	St. Augustine	0	0	0	0	0	0
32	Matanzas	0	0	0	0	0	0
33	Ponce De Leon	0	0	0	1	0	0
34	Sebastian	1	1	1	1	1	1
35	Boca Raton	0	1	0	1	0	1
36	Hillsboro	1	1	1	1	1	1

(Continued)

[1] 0 indicates stability; 1 indicates instability.

Table 13 (Concluded)

Inlet Number	Inlet Name	ϕ_1	ϕ_2	ψ_1	ψ_2	Φ	Ψ
37	Redfish	0	0	0	1	0	1
38	Gasparilla	0	0	0	0	0	0
39	Stump	0	0	1	0	0	1
40	Midnight	1	0	1	0	1	1
41	Big Sarasota	0	0	0	0	0	0
42	Longboat	0	0	0	1	0	1
43	Pass A Grille-S	0	0	0	1	0	0
44	Pass A Grille-N	0	0	0	0	0	0
45	Clearwater	1	0	0	1	1	1
46	San Luis	0	0	0	1	0	0
47	Bolinas	0	1	1	0	1	1
48	Drakes	0	0	1	0	0	0
49	Siuslaw	0	1	0	1	1	0
50	Siletz	0	0	0	0	0	0
51	Netarts	0	0	0	0	0	0

Absolute Values of Inlet Stability

65. In the previous section, emphasis was placed on analysis of inlet stability relative to size of the inlet. Primary benefits of such an approach is the scaling of inlet variation. One problem, however, is that large, in absolute magnitude, changes in inlets of large size are inherently ranked lower than large changes in small inlets. For this reason, it is necessary to consider changes in terms of magnitude, unnormalized by any size factor.

66. The approach taken is to calculate the following rates, all in feet per month: (a) the time rate of change in width, dW/dt ; (b) the time rate of change in channel length, dL/dt ; (c) the time rate of change in mean inlet channel position, dP/dt[1] ; and (d) the time rate of change in channel orientation, dO/dt[2] . The absolute value of each index is taken and the

[1] $dP/dt = \eta/\Delta t$.

[2] $dO/dt = \epsilon/\Delta t$.

maximum rate selected for analysis (Table 14). As before, hydraulic and geographic stability will be considered individually, and then together.

Hydraulic stability

67. Of the two hydraulic parameters W and L, $|dW/dt|_{max}$[1] ranges only 75 percent of the range in dL/dt. The range in dW/dt is from 0 to 390 ft/month. The range in dL/dt is from 0 to 527 ft/month. In general, values of both dW/dt and dL/dt are less than 200 ft/month (Figure 15). Thirty-three inlets have dW/dt and dL/dt less than 100 ft/month. Taking 100 ft/month as an arbitrary limit for stability appears fairly reasonable considering possible photogrammetric errors and that the rate plotted is the maximum observed.

68. Although many inlets exhibit trends, it should be emphasized that this maximum value should not be considered as a trend rate. Using 100 ft/month as a limit, 11 inlets are W[2]-stable, 3 are L-stable, 4 are W-L-unstable, and the remainder are stable (Table 15).

Positional stability

69. The range in dP/dt is from 0 to 380 ft/month, and the range in dO/dt is from 0 to 275 ft/month (Figure 16). Accepting 100 ft/month as a limit for stability, 3 inlets are O-stable, 2 inlets are P-stable, 5 inlets are O-P unstable, and the remaining 41 inlets are stable. Inlets are listed by stability category in Table 16. Review of Figure 16 indicates, with the exception of two inlets, a possible relationship between maximum values of dP/dt and dO/dt exists. It is interesting to note that as dP/dt becomes large, dO/dt tends to stabilize. More data are required, however, to confirm such a correspondence.

Hydraulic stability - geographic stability variations

70. Consideration of the relationship between absolute hydraulic and geographic stability aspects will follow the general outline used in the relative value analysis. Stability limits established previously will be applied.

---

1 For the remainder of the chapter, the absolute value sign and subscript max will be dropped.

2 The letters W, L, P, and O will be used to abbreviate the time variation of width, length, position, and orientation in the following text.

Table 14

Absolute Values of Inlet Stability

Inlet Number	Inlet Name	dW/dt	dL/dt	dP/dt	dO/dt
1	Moriches	38	42	85	27
2	Fire Island	76	133	91	49
3	Brigantine	84	43	77	73
4	Corson	299	99	60	63
5	Townsend	12	164	58	64
6	Hereford	124	118	54	40
7	Gargathy	10	18	20	15
8	Metomkin	58	527	155	274
9	Wachapreague	90	268	287	140
10	Oregon	105	33	20	41
11	Hatteras	389	162	199	127
12	Beaufort	51	41	60	21
13	Bogue	88	39	30	16
14	New Topsail	41	60	165	85
15	Rich	179	225	133	271
16	Carolina Beach	20	51	20	40
17	Lockwoods Folly	111	164	116	88
18	Shallotte	42	314	95	113
19	Tubbs	36	280	379	105
20	Little River	83	259	100	80
21	Murrells	43	238	145	93
22	North	73	35	67	36
23	South Santee	7	65	51	55
24	Price	6	20	31	20
25	Capers	4	38	17	17
26	Dewees	47	386	64	128
27	Lighthouse	13	14	6	12
28	Nassau-N	3	83	31	23
29	Nassau-S	3	35	16	14
30	Ft. George	126	60	41	26
31	St. Augustine	14	46	27	24
32	Matanzas	3	27	14	13
33	Ponce De Leon	35	58	21	31
34	Sebastian	5	18	4	6
35	Boca Raton	1	8	2	4
36	Hillsboro	17	80	16	60

(Continued)

Table 14 (Concluded)

Inlet Number	Inlet Name	dW/dt	dL/dt	dP/dt	dO/dt
37	Redfish	5	32	17	20
38	Gasparilla	21	20	38	20
39	Stump	11	24	96	19
40	Midnight	8	17	17	9
41	Big Sarasota	5	16	12	8
42	Longboat	5	34	33	50
43	Pass A Grille-S	2	21	9	7
44	Pass A Grille-N	2	22	4	8
45	Clearwater	17	165	60	37
46	San Luis	18	137	60	18
47	Bolinas	4	18	16	10
48	Drakes	30	7	72	12
49	Siuslaw	13	89	41	23
50	Siletz	0	4	3	1
51	Netarts	5	4	20	25

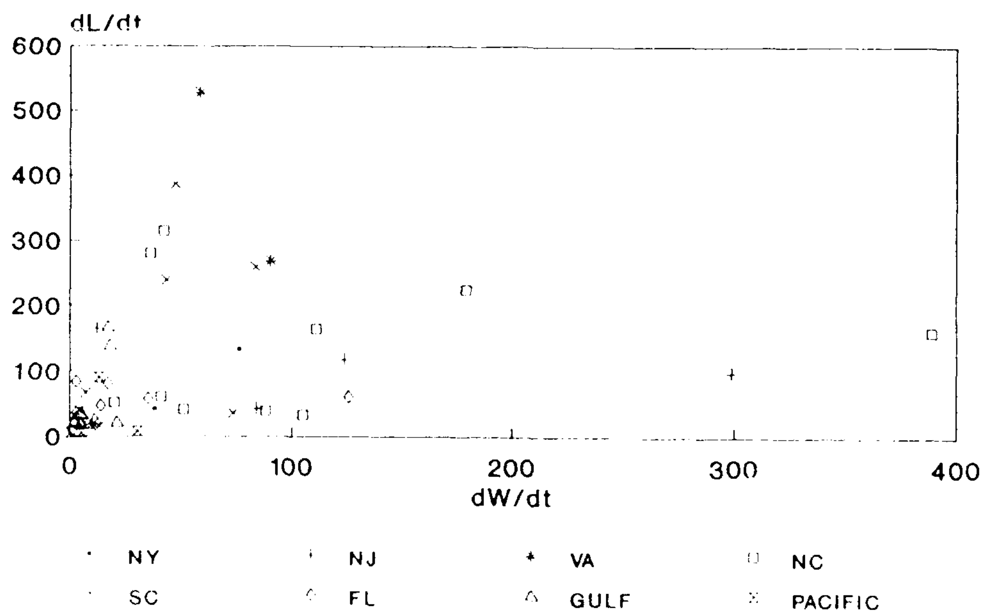

Figure 15. Plot of dL/dt versus dW/dt

Table 15

Stability Classification Based on W and L

Inlet Number	Inlet Name	dW/dt & dL/dt Stable	dW/dt Stable dL/dt Unstable	dW/dt Unstable dL/dt Stable	dW/dt & dL/dt Unstable
1	Moriches	x			
2	Fire Island		x		
3	Brigantine	x			
4	Corson			x	
5	Townsend		x		
6	Hereford				x
7	Gargathy	x			
8	Metomkin		x		
9	Wachapreague		x		
10	Oregon			x	
11	Hatteras				x
12	Beaufort	x			
13	Bogue	x			
14	New Topsail	x			
15	Rich				x
16	Carolina Beach	x			
17	Lockwoods Folly				x
18	Shallotte		x		
19	Tubbs		x		
20	Little River		x		
21	Murrells		x		
22	North	x			
23	South Santee	x			
24	Price	x			
25	Capers	x			
26	Dewees		x		
27	Lighthouse	x			
28	Nassau-N	x			
29	Nassau-S	x			
30	Ft. George			x	
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian	x			
35	Boca Raton	x			
36	Hillsboro	x			

(Continued)

Table 15 (Concluded)

Inlet Number	Inlet Name	dW/dt & dL/dt Stable	dW/dt Stable dL/dt Unstable	dW/dt Unstable dL/dt Stable	dW/dt & dL/dt Unstable
37	Redfish	x			
38	Gasparilla	x			
39	Stump	x			
40	Midnight	x			
41	Big Sarasota	x			
42	Longboat	x			
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater		x		
46	San Luis		x		
47	Bolinas	x			
48	Drakes	x			
49	Siuslaw	x			
50	Siletz	x			
51	Netarts	x			

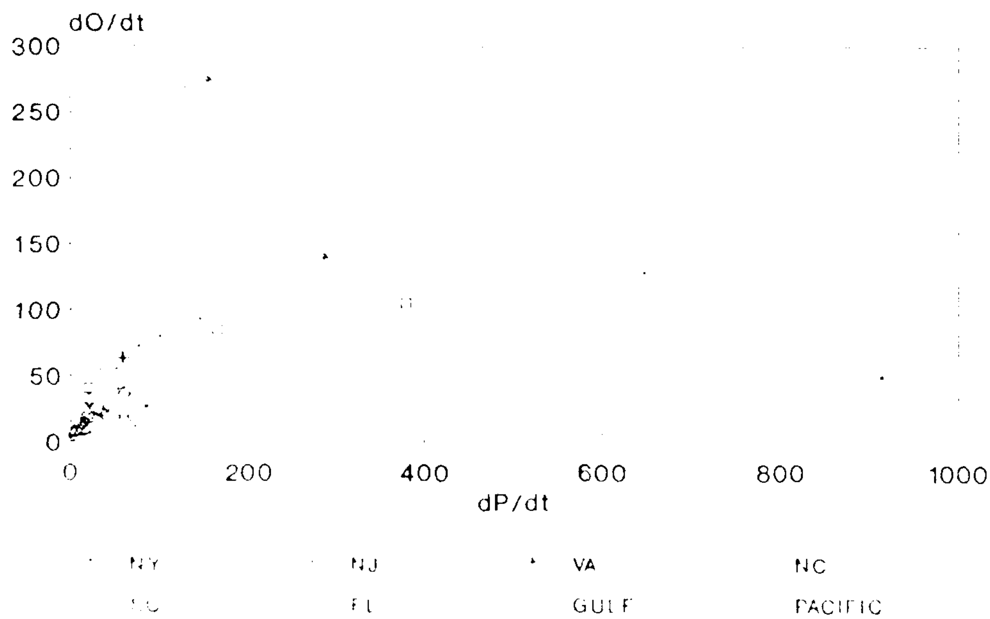

Figure 16. Plot of dO/dt versus dP/dt

Table 16

Stability Classification Based on P and O

Inlet Number	Inlet Name	dP/dt & dO/dt Stable	dP/dt Stable dO/dt Unstable	dP/dt Unstable dO/dt Stable	dP/dt & dO/dt Unstable
1	Moriches	x			
2	Fire Island	x			
3	Brigantine	x			
4	Corson	x			
5	Townsend	x			
6	Hereford	x			
7	Gargathy	x			
8	Metomkin				x
9	Wachapreague				x
10	Oregon	x			
11	Hatteras				x
12	Beaufort	x			
13	Bogue	x			
14	New Topsail			x	
15	Rich				x
16	Carolina Beach	x			
17	Lockwoods Folly			x	
18	Shallotte		x		
19	Tubbs				x
20	Little River	x			
21	Murrells			x	
22	North	x			
23	South Santee	x			
24	Price	x			
25	Capers	x			
26	Dewees		x		
27	Lighthouse	x			
28	Nassau-N	x			
29	Nassau-S	x			
30	Ft. George	x			
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian	x			
35	Boca Raton	x			
36	Hillsboro	x			

(Continued)

Table 16 (Concluded)

Inlet Number	Inlet Name	dP/dt & dO/dt Stable	dP/dt Stable dO/dt Unstable	dP/dt Unstable dO/dt Stable	dP/dt & dO/dt Unstable
37	Redfish	x			
38	Gasparilla	x			
39	Stump	x			
40	Midnight	x			
41	Big Sarasota	x			
42	Longboat	x			
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater	x			
46	San Luis	x			
47	Bolinas	x			
48	Drakes	x			
49	Siuslaw	x			
50	Siletz	x			
51	Netarts	x			

71. When dW/dt is plotted against dP/dt (Figure 17), most inlets appear stable. Five inlets are W-stable (Table 17). Only four inlets are P-stable, and three inlets are W-P-unstable. It is interesting to note that inlets with the largest dP/dt are width stable, whereas inlets that undergo the most rapid changes in width are only mildly P-unstable.

72. Table 18 and a plot of dW/dt and dO/dt (Figure 18) again show that most inlets are W-O-stable. Five inlets are O-stable, five are W-stable, and two are W-O-unstable. Inlets with the maximum dO/dt values are normally W-stable. Inlets with large dW/dt values appear to have low values of dO/dt with the exception of one case.

73. The relationship between dL/dt and dP/dt is shown in Figure 19. There are somewhat fewer inlets classified completely stable than in the relationships discussed previously. However, only one inlet is L-stable; eight are P-stable and seven are L-P-unstable (Table 19).

74. When dL/dt is plotted against dO/dt (Figure 20), a nearly linear relationship appears. There are no L-stable inlets; 8 are O-stable, and 7 are L-O-unstable (Table 20). The remaining 36 inlets

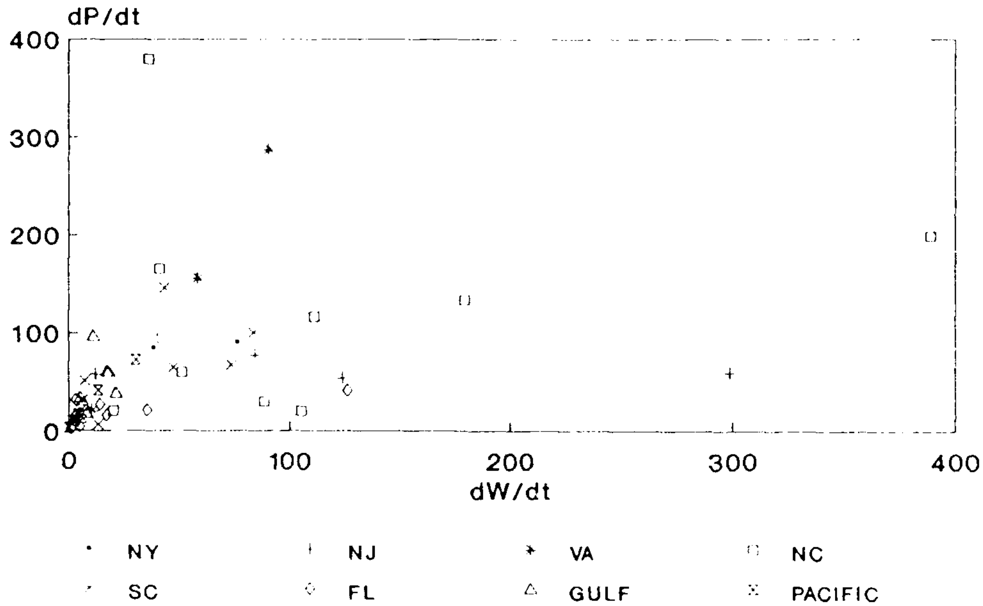

Figure 17. Plot of dP/dt versus dW/dt

Table 17

Stability Classification Based on W and P

Inlet Number	Inlet Name	dW/dt & dP/dt Stable	dW/dt Stable dP/dt Unstable	dW/dt Unstable dP/dt Stable	dW/dt & dP/dt Unstable
1	Moriches	x			
2	Fire Island	x			
3	Brigantine	x			
4	Corson			x	
5	Townsend	x			
6	Hereford			x	
7	Gargathy	x			
8	Metomkin		x		
9	Wachapreague		x		
10	Oregon			x	
11	Hatteras				x
12	Beaufort	x			

(Continued)

Table 17 (Concluded)

Inlet Number	Inlet Name	dW/dt & dP/dt Stable	dW/dt Stable dP/dt Unstable	dW/dt Unstable dP/dt Stable	dW/dt & dP/dt Unstable
13	Bogue	x			
14	New Topsail		x		
15	Rich				x
16	Carolina Beach	x			
17	Lockwoods Folly				x
18	Shallotte	x			
19	Tubbs		x		
20	Little River	x			
21	Murrells		x		
22	North	x			
23	South Santee	x			
24	Price	x			
25	Capers	x			
26	Dewees	x			
27	Lighthouse	x			
28	Nassau-N	x			
29	Nassau-S	x			
30	Ft. George			x	
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian	x			
35	Boca Raton	x			
36	Hillsboro	x			
37	Redfish	x			
38	Gasparilla	x			
39	Stump	x			
40	Midnight	x			
41	Big Sarasota	x			
42	Longboat	x			
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater	x			
46	San Luis	x			
47	Bolinas	x			
48	Drakes	x			
49	Siuslaw	x			
50	Siletz	x			
51	Netarts	x			

Table 18

Stability Classification Based on W and O

Inlet Number	Inlet Name	dW/dt & dO/dt Stable	dW/dt Stable dO/dt Unstable	dW/dt Unstable dO/dt Stable	dW/dt & dO/dt Unstable
1	Moriches	x			
2	Fire Island	x			
3	Brigantine	x			
4	Corson			x	
5	Townsend	x			
6	Hereford			x	
7	Gargathy	x			
8	Metomkin		x		
9	Wachapreague		x		
10	Oregon			x	
11	Hatteras				x
12	Beaufort	x			
13	Bogue	x			
14	New Topsail	x			
15	Rich				x
16	Carolina Beach	x			
17	Lockwoods Folly			x	
18	Shallotte		x		
19	Tubbs		x		
20	Little River	x			
21	Murrells	x			
22	North	x			
23	South Santee	x			
24	Price	x			
25	Capers	x			
26	Dewees		x		
27	Lighthouse	x			
28	Nassau-N	x			
29	Nassau-S	x			
30	Ft George			x	
31	St Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian	x			
35	Boca Raton	x			
36	Hillsboro	x			

(Continued)

Table 18 (Concluded)

Inlet Number	Inlet Name	dW/dt & dO/dt Stable	dW/dt Stable dO/dt Unstable	dW/dt Unstable dO/dt Stable	dW/dt & dO/dt Unstable
37	Redfish	x			
38	Gasparilla	x			
39	Stump	x			
40	Midnight	x			
41	Big Sarasota	x			
42	Longboat	x			
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater	x			
46	San Luis	x			
47	Bolinas	x			
48	Drakes	x			
49	Siuslaw	x			
50	Siletz	x			
51	Netarts	x			

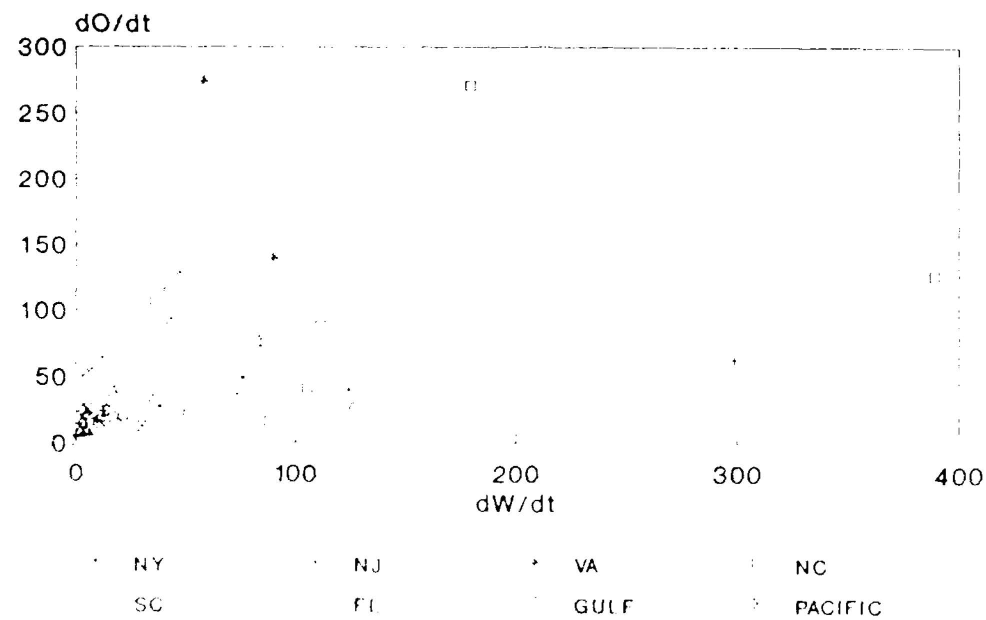

Figure 18. Plot of dO/dt versus dW/dt

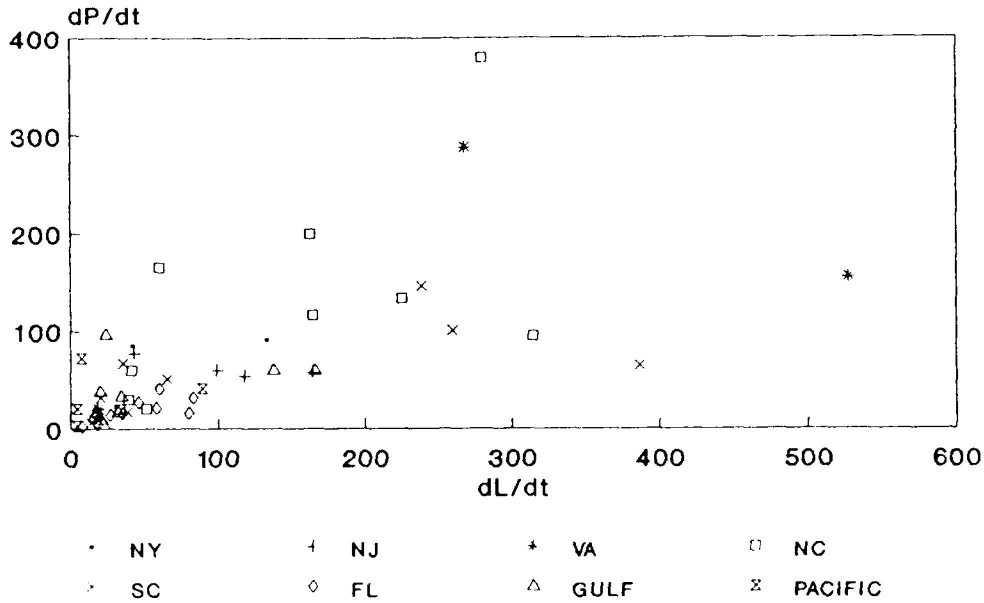

Figure 19. Plot of dP/dt versus dL/dt

Table 19

Stability Classification Based on L and P

Inlet Number	Inlet Name	dL/dt & dP/dt Stable	dL/dt Stable dP/dt Unstable	dL/dt Unstable dP/dt Stable	dL/dt & dP/dt Unstable
1	Moriches	x			
2	Fire Island			x	
3	Brigantine	x			
4	Corson	x			
5	Townsend			x	
6	Hereford			x	
7	Gargathy	x			
8	Metomkin				x
9	Wachapreague				x
10	Oregon	x			
11	Hatteras				x
12	Beaufort	x			

(Continued)

Table 19 (Concluded)

Inlet Number	Inlet Name	dL/dt & dP/dt Stable	dL/dt Stable dP/dt Unstable	dL/dt Unstable dP/dt Stable	dL/dt & dP/dt Unstable
13	Bogue	x			
14	New Topsail		x		
15	Rich				x
16	Carolina Beach	x			
17	Lockwoods Folly				x
18	Shallotte			x	
19	Tubbs				x
20	Little River			x	
21	Murrells				x
22	North	x			
23	South Santee	x			
24	Price	x			
25	Capers	x			
26	Dewees			x	
27	Lighthouse	x			
28	Nassau-N	x			
29	Nassau-S	x			
30	Ft. George	x			
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian	x			
35	Boca Raton	x			
36	Hillsboro	x			
37	Redfish	x			
38	Gasparilla	x			
39	Stump	x			
40	Midnight	x			
41	Big Sarasota	x			
42	Longboat	x			
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater			x	
46	San Luis			x	
47	Bolinas	x			
48	Drakes	x			
49	Siuslaw	x			
50	Siletz	x			
51	Netarts	x			

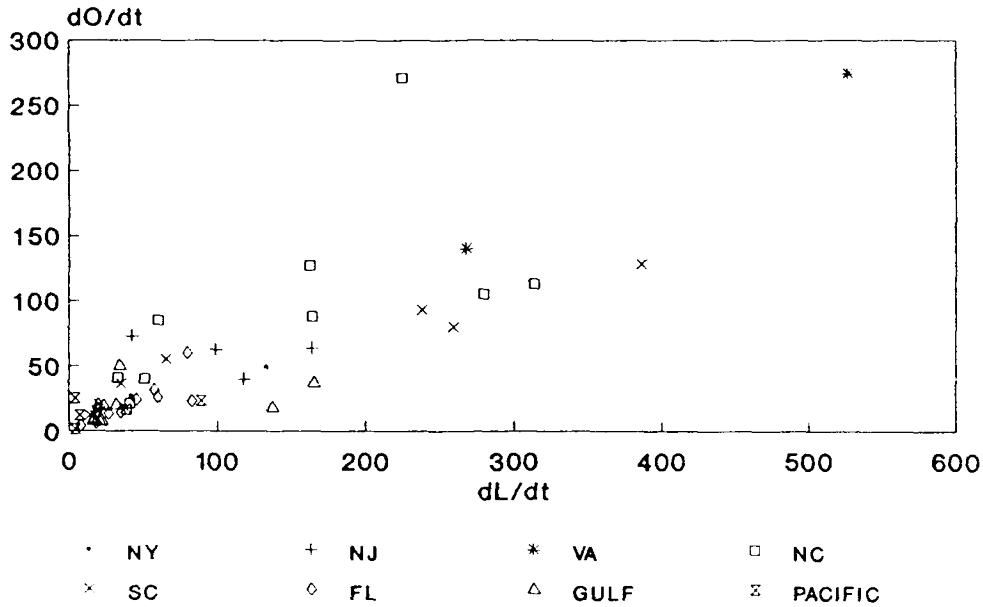

Figure 20. Plot of dO/dt versus dL/dt

Table 20

Stability Classification Based on L and O

Inlet Number	Inlet Name	dL/dt & dO/dt Stable	dL/dt Stable dO/dt Unstable	dL/dt Unstable dO/dt Stable	dL/dt & dO/dt Unstable
1	Moriches	x			
2	Fire Island			x	
3	Brigantine	x			
4	Corson	x			
5	Townsend			x	
6	Hereford			x	
7	Gargathy	x			
8	Metomkin				x
9	Wachapreague				x
10	Oregon	x			
11	Hatteras				x
12	Beaufort	x			

(Continued)

Table 20 (Concluded)

Inlet Number	Inlet Name	dL/dt & dO/dt Stable	dL/dt Stable dO/dt Unstable	dL/dt Unstable dO/dt Stable	dL/dt & dO/dt Unstable
13	Bogue	x			
14	New Topsail	x			
15	Rich				x
16	Carolina Beach	x			
17	Lockwoods Folly			x	
18	Shallotte				x
19	Tubbs				x
20	Little River			x	
21	Murrells			x	
22	North	x			
23	South Santee	x			
24	Price	x			
25	Capers	x			
26	Dewees				x
27	Lighthouse	x			
28	Nassau-N	x			
29	Nassau-S	x			
30	Ft. George	x			
31	St. Augustine	x			
32	Matanzas	x			
33	Ponce De Leon	x			
34	Sebastian	x			
35	Boca Raton	x			
36	Hillsboro	x			
37	Redfish	x			
38	Gasparilla	x			
39	Stump	x			
40	Midnight	x			
41	Big Sarasota	x			
42	Longboat	x			
43	Pass A Grille-S	x			
44	Pass A Grille-N	x			
45	Clearwater			x	
46	San Luis			x	
47	Bolinas	x			
48	Drakes	x			
49	Siuslaw	x			
50	Siletz	x			
51	Netarts	x			

are stable. The relationship indicates that the amount of swing in an inlet channel is related to a change in channel length. Geometry to a large degree would demand this.

Discussion

75. Graphs and tables in this section show the instabilities of inlets in terms of maximum time ratio of change of the basic parameters shown. In contrast to analyses discussed in earlier sections, most inlets appear in the completely stable categories, perhaps due to selection of a stability value that is too high. It should be emphasized again that this is a maximum rate, and in most cases a good deal higher than the normal rates calculated. For purposes of display, it is an adequate delimiter.

76. Table 21 lists the number of inlets in each of the 16 categories of stable-unstable conditions that can be formed by parameter pairs chosen from dW/dt , dL/dt , dP/dt , and dO/dt to show relationships between hydraulic and geographic stability aspects. Table 22 provides a summary of stability, by inlet, under each of the four categories.

Table 21

Summary of Absolute Geographic and Hydraulic Stability Parameters

Geographic Parameters	Hydraulic Parameters			
	W-Stable	W-Unstable	L-Stable	L-Unstable
P-stable	39	4	35	8
P-unstable	5	3	1	7
O-stable	39	5	36	8
O-unstable	5	2	0	7

Table 22

Absolute Stability of Selected Inlets

Inlet Number	Inlet Name	dW/dt	dL/dt	dP/dt	dO/dt
1	Moriches	0*	0	0	0
2	Fire Island	0	1	0	0
3	Brigantine	0	0	0	0
4	Corson	1	0	0	0
5	Townsend	0	1	0	0
6	Hereford	1	1	0	0
7	Gargathy	0	0	0	0
8	Metomkin	0	1	1	1
9	Wachapreague	0	1	1	1
10	Oregon	1	0	0	0
11	Hatteras	1	1	1	1
12	Beaufort	0	0	0	0
13	Bogue	0	0	0	0
14	New Topsail	0	0	1	0
15	Rich	1	1	1	1
16	Carolina Beach	0	0	0	0
17	Lockwoods Folly	1	1	1	0
18	Shallotte	0	1	0	1
19	Tubbs	0	1	1	1
20	Little River	0	1	0	0
21	Murrells	0	1	1	0
22	North	0	0	0	0
23	South Santee	0	0	0	0
24	Price	0	0	0	0
25	Capers	0	0	0	0
26	Dewees	0	1	0	1
27	Lighthouse	0	0	0	0
28	Nassau-N	0	0	0	0
29	Nassau-S	0	0	0	0
30	Ft. George	1	0	0	0
31	St. Augustine	0	0	0	0
32	Matanzas	0	0	0	0
33	Ponce De Leon	0	0	0	0
34	Sebastian	0	0	0	0
35	Boca Raton	0	0	0	0
36	Hillsboro	0	0	0	0

(Continued)

* 0 indicates stability and 1 indicates instability.

Table 22 (Concluded)

Inlet Number	Inlet Name	dW/dt	dL/dt	dP/dt	dO/dt
37	Redfish	0	0	0	0
38	Gasparilla	0	0	0	0
39	Stump	0	0	0	0
40	Midnight	0	0	0	0
41	Big Sarasota	0	0	0	0
42	Longboat	0	0	0	0
43	Pass A Grille-S	0	0	0	0
44	Pass A Grille-N	0	0	0	0
45	Clearwater	0	1	0	0
46	San Luis	0	1	0	0
47	Bolinas	0	0	0	0
48	Drakes	0	0	0	0
49	Siuslaw	0	0	0	0
50	Siletz	0	0	0	0
51	Netarts	0	0	0	0

PART VI: REGIONAL VARIATIONS IN INLET STABILITY

77. In Parts IV and V, emphasis was placed on the definition and measurement of inlet stability, analysis of the character of time variation in stability characteristics, and examination of relative and absolute measures of hydraulic and geographic stability. Attention is now given to an examination of regional patterns in inlet stability.

78. Prior to a region-by-region discussion, some general remarks are pertinent. Examination of the plots of W, L, η, and ϵ (Appendix C) shows that as a general rule there is no strong correlation in the temporal variation of any of the parameters, even between inlets fairly closely located. For short periods of time, there may be a correlation, but in terms of the overall period of study, a lack of correlation is the rule. However, if overall trends in W, L, η, and ϵ are examined, some regional patterns are apparent (Table 23). Assignment of regional patterns is based on the character of a majority of inlets in any region.

79. In addition to an analysis of trends, characteristics of the regions in terms of the relative and absolute parameters developed in Part V are also discussed. Reference can be made to Tables 13 and 22 for summaries of the relative and absolute parameters.

Regional Characteristics

New York

80. The two New York inlets studied (Moriches and Fire Island) tend to be highly unstable in both geographic and hydraulic terms. Both inlets have been dredged and are structured. It is impossible to separate natural variations from response of the inlet to engineering modifications.

New Jersey

81. In terms of the relative parameters defined, New Jersey inlets are hydraulically and geographically unstable. Trends, however, are somewhat mixed, and only a weak regionality is suggested. These inlets tend to have decreasing widths and lengths and to migrate downcoast. The inlets, though

Table 23

Regional Patterns of Inlet Variability

Inlet Number	Inlet Name	W	L	η
		New York		
1	Moriches	-	I[1]	DC
2	Fire Island	I	D	U
		New Jersey		
3	Brigantine	D	D	U
4	Corson	I	D	DC
5	Townsend	-	-	-
6	Hereford	D	I	DC
		Virginia		
7	Gargathy	D	-	DC
8	Metomkin	I	D	-
9	Wachapreague	D	I	-
		North Carolina		
10	Oregon	D	I	U
11	Hatteras	I	D	DC
12	Beaufort	D	D	-
13	Bogue	D	I	U
14	New Topsail	D	I	DC
15	Rich	D	I	U
16	Carolina Beach	-	I	DC
17	Lockwoods Folly	-	D	DC
18	Shallotte	I	I	U
19	Tubbs	D	I	DC
		South Carolina		
20	Little River	I	D	DC
21	Murrells	D	I	DC
22	North	I	D	U
23	South Santee	I	D	U
24	Price	-	D	-
25	Capers	D	I	DC
26	Dewees	-	I	DC
27	Lighthouse	I	I	U

(Continued)

[1] I indicates increasing W or L , D indicates decreasing W or L , U indicates upcoast movement of η , and DC indicates downcoast movement of η .

Table 23 (Concluded)

Inlet Number	Inlet Name	W	L	η
		East Florida		
28	Nassau-N	D	I	DC
29	Nassau-S	D	D	U
30	Ft George	D	-	D
31	St Augustine	-	D	DC
32	Matanzas	-	-	DC
33	Ponce De Leon	I	-	DC
34	Sebastian	I	I	-
35	Boca Raton	-	D	-
36	Hillsboro	I	I	DC
		Gulf Coast		
37	Redfish	-	I	-
38	Gasparilla	I	-	U
39	Stump	D	I	DC
40	Midnight	-	-	DC
41	Big Sarasota	I	D	-
42	Longboat	I	I	DC
43	Pass A Grille-S	-	D	U
44	Fass A Grille-N	-	I	DC
45	Clearwater	D	D	-
46	San Luis	I	D	DC
		West Coast		
47	Bolinas	-	I	-
48	Drakes	-	I	U
49	Siuslaw	-	D	U
50	Siletz	-	I	DC
51	Netarts	I	-	DC

unstable in relative terms, do not exhibit high values in absolute magnitude, with maximum rates of change normally much lower than 100 feet/month.

Virginia

82. Two of the three Virginia inlets show decreasing widths and no regional pattern for length. Movement shows no trend. In terms of the relative parameters defined, the inlets are unstable in length and orientation but stable in width and location. Metomkin and Wachapreague Inlets show large maximum rates of change in length, location, and orientation.

North Carolina

83. Examination of Table 23 suggests that the North Carolina inlets could be divided into two groups. One group contains the inlets between Oregon and New Topsail; the other includes the inlets between Rich and Tubbs. Inlets in the first group show a decreasing trend in width, an increasing trend in length, and a mixed trend in movement. In terms of relative stability, however, widths are stable, lengths are unstable, position is stable, and orientation is unstable. Oregon, Hatteras, and New Topsail have large rates of change in terms of the absolute stability.

84. Inlets in the second group show mixed trends in width, but show trends toward increased length; movement is mixed. In relative stability, width and length are unstable, and the inlets are both position and orientationally unstable. Lockwoods Folly, Shallotte, and Tubbs show large absolute rates of change.

South Carolina

85. South Carolina inlets exhibit a trend toward increasing widths. This trend is more pronounced for the more northern inlets in this group (Little River to South Santee). These four inlets tend to have decreasing lengths. Movement is mixed. The four inlets in the southern part of the group (Price to Lighthouse) have mixed trends in width, but show increasing lengths. Movement is again mixed.

86. As a group, the South Carolina inlets are width stable in terms of relative parameters but show a mix of length and position stability characteristics. The inlets tend to be orientationally unstable. The northern four inlets are more positionally unstable than the southern four inlets. Little River, Murrells, and Dewees show large values in terms of absolute stability.

East Florida

87. The more northern Florida inlets (Nassau to St. Augustine) show a trend of decreasing widths. Trends in length and movement are mixed. The southern inlets (Matanzas to Hillsboro) have a trend toward increasing width and downcoast movement. In terms of relative parameters, the Florida inlets as a group are width stable, position stable, and orientationally unstable. The southern group of inlets tends to be more unstable in relative length and

orientation. Many of these inlets are small and likewise have small rates of change in terms of the absolute parameters.

Gulf coast

88. The gulf coast inlets show no strong regional trends. In terms of relative parameters, the inlets tend to be width and length stable and stable in position and orientation as well. These inlets have fairly small rates of change in the absolute parameters.

West coast

89. These inlets show major trend in width, but tend to show a trend toward increasing lengths. They are stable in terms of relative and absolute parameters. It should be noted that both man-made controls and geologic limitations may tend to restrict the variability of these inlets.

Discussion

90. Although no strong temporal correlation exists between inlets located in proximity to each other, regional patterns in the trends of many of the stability patterns can be seen. It should be considered that these regional patterns are based on the sample of inlets studied. There is no assurance, however, that if additional inlets were added to the study, the patterns would remain.

91. It is interesting to note an apparent contradiction in terms in the discussion of the inlet trends by region. In a few instances, regions exhibit a trend in a parameter such as width or length, but the relative parameters are classified as stable. This can arise if the trend is small, in which case $\phi_1 = W_{max}/W_{min}$ will be small. Likewise, it is possible for a relative parameter to be unstable with no trend. The apparent contradictions are thus not only possible but logical.

92. An initial expectation of this project was that regional correlation in trends would be found. As shown here, there is a regionality in the trends of certain parameters, but there is no strong correlation. It is perhaps worthwhile to speculate on the reasons why the correlations should not be expected.

93. If a fairly straight coast with uniform offshore slopes and a regionally homogeneous wave climate is considered, a reasonable expectation is that the longshore transport quantities and directions are homogeneous. Given a long-term variability in wave climate, a corresponding variability in longshore transport is expected; however, as long as the wave climate remains homogeneous over the region, so should the longshore transport.

94. Bruun, Gerritsen, and Bhakta (1975) give substantial evidence that inlets can bypass or trap sediment in a variety of ways. If the hypothetical coast contains inlets of differing transport handling characteristics spaced at fairly close intervals, it becomes evident that individual inlet response to a homogeneous wave climate can be quite inhomogeneous. Consider the example of two inlets located fairly close to each and a longshore transport that would be nearly balanced, if there were no inlets. If net transport is from north to south and the more northerly of the two inlets is efficient at trapping sand, it is conceivable that the southern inlet will have a local net drift in a direction opposite to the regional trend because the inlet upstream has trapped southbound sediment. Thus, the two inlets might well respond in opposite directional senses. It is evident that the type of inlet (based on transport and trapping characteristics) and the spacing of inlets are critical to local inlet response, and that the response of inlets to a regionally uniform wave climate can be mixed. Regional trends might well be expected only where inlet characteristics are fairly uniform, inlet spacing is large, and longshore transport is fairly dominant in one direction.

PART VII: SUMMARY

95. The principal objective of the research task summarized in this report was to establish a quantitative database of stability characteristics of selected US tidal inlets. These stability data are intended for use in comparison to hydraulic and morphologic characteristics of these inlets to produce a better understanding of the interrelationships among these three principal aspects of inlet variation.

96. Because aerial photographs are the only source of information with sufficient temporal coverage to provide a stability database, the analyses must involve only those factors that can be consistently interpreted on the photographs. This necessarily limits the range of analysis because no depth measurements can be made. Inference of stability characteristics must rely on such measures as widths and lengths of features in the horizontal plane and the geographical location of features. Information on the location and relative depth of subaqueous features depends on photointerpretation of wave refraction-diffraction and breaking, turbidity, and shoal patterns in clear water. Although elements such as cross-sectional areas cannot be determined, influence of hydraulic instability can be drawn from other measures.

97. Four stability indices were defined and measured. These include minimum inlet width W and channel length L. Change in the geographical position and orientation of the inlet channel were defined by the indices η and ϵ. Analysis of these indices show that they are sufficient to express a wide range of inlet variations and can be consistently defined.

98. An important aspect of the stability analysis is the range in instabilities observed. It was recognized that the stability of an inlet is to a large degree determined by inlet size and use. Two approaches appeared necessary to examine inlet stability. The first approach was definition of six relative stability parameters. These parameters were termed relative because they are in essence normalized by a factor indicative of inlet size. The second approach taken was to express inlet change in terms of absolute parameters that measure change in terms of magnitude (not normalized by inlet size).

99. Relative parameters include three hydraulic parameters ϕ_1 , ϕ_2 , and Φ . The first is a width parameter, the second a length parameter, and the third is a product of the first two. The other three parameters are geographical parameters. The first, ψ_1 , measures a positional movement in the channel; the second, ψ_2 , measures changes in orientation; and the third, Ψ , is a product of the first two. Thus, combinations of the six parameters can be used to display various stability characteristics. In the analyses presented, a stability limit was chosen, and the inlets classified as stable or unstable on the basis of this value. The stability limit is somewhat arbitrary, but then so must be any such delineation. It should be noted that most combinations of stable-unstable for varying pairs of parameters occurred.

100. Absolute parameters were defined as maximum observed rates of change. Four parameters were defined; dW/dt , dL/dt , dP/dt , and dO/dt . The first two refer to inlet width and channel length changes; the second two refer to changes in position and orientation, respectively. The same procedures used with relative parameters were used to display the interrelationships among absolute parameters. Although a value of 100 feet/month was selected as a stability limit, it is interesting to note that most values are below this rate.

101. Consideration was also given to the pattern of change in the parameters. Most inlets exhibit either a long-term trend or long-period cycle for the parameters derived, but a significant number do exhibit shorter period changes. It is interesting that a trend in one parameter at an inlet does not necessarily imply trends in other parameters.

102. When the time variation of parameters for inlets located in close proximity is analyzed, strong correlations are not apparent. However, if only general trends are considered, regional patterns do emerge. Regionality of inlet movement is only infrequently observed.

103. Tidal inlet geomorphic changes presented in Appendices B and C can be used directly to estimate changes expected for the selected inlets. For example, a knowledge of historical channel position and orientation would be valuable to an engineer or coastal planner who might be considering construction in the vicinity of the inlet. However, the primary use of the data presented in this report (other than the analyses performed for this

report) will be in future studies of relationships between inlet geomorphic changes and appropriate hydraulic parameters (tidal current velocities; wave height, period, and direction; storm surge; sediment transport estimates; etc.).

104. From the analyses presented, it is evident that a range of inlet instabilities is not only possible but frequently observed. The lack of correlation for inlet response to presumably regionally homogeneous wave climates suggests that the morphology and hydraulics of specific inlets have great influence on the response of the inlet to wave-induced sediment transport. It remains for future research to show whether the detailed response is predictable. The regionality of trends that was found suggests, however, that over the long term, environmental factors exert substantial control over the evolution of inlets.

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APPENDIX A: LISTING OF AERIAL PHOTOGRAPHS USED IN INVESTIGATION

Appendix A consists of a listing of all aerial photographs used in the investigation. Dates of each photograph are listed along with the condition of the inlet at the time of the flight.

Table A1

Summary of Aerial Photographic Data

Inlet Number	Inlet Name	Date of Photo	Condition
1	Moriches, NY	Aug 44	no structures
		Sep 47	no structures
		Apr 54	jetties[1]
		Mar 55	
		May 61	
		Mar 62	
		Jun 63	
		Mar 66	
		Jun 63	
		Mar 66	
		Oct 69	
		May 70	
		May 71	
2	Fire Island, NY	May 55	left jetty
		Apr 57	
		Jan 61	
		Mar 62	
		Oct 63	
		May 64	
		Feb 65	
		Feb 66	
		May 70	
3	Brigantine, NJ	Mar 40	no structures
		Apr 50	
		Apr 54	
		Jan 62	
		Jul 63	
		Jun 68	
4	Corson, NJ	Feb 40	right groins
		Nov 49	right groins
		Apr 50	right groins
		Mar 51	right groins

(Continued)

[1] Moriches Inlet was artificially reopened after natural closing after Sep 47.

(Sheet 1 of 10)

Table A1 (Continued)

Inlet Number	Inlet Name	Date of Photo	Condition
4	Corson, NJ (Cont'd)	Oct 52	right groins
		Jun 53	
		Apr 54	
		Mar 55	
		Jun 56	
		Nov 57	
		Apr 59	
		Jun 60	
		Sep 61	
		Jun 63	
		May 65	
		May 66	
		Sep 67	
		Apr 69	
		Mar 70	
		Feb 71	↓
5	Townsend, NJ	Apr 40	right groins & seawall
		Aug 44	
		Apr 50	
		Mar 51	
		Mar 55	
		Jun 56	
		May 61	
		Mar 62	
		May 63	
		Sep 67	
		Mar 70	
		Apr 73	↓
6	Hereford, NJ	Apr 40	no structures
		Aug 44	
		Mar 51	
		Apr 54	
		Mar 55	
		Jun 56	↓
		Mar 62	right groins & seawall
		Apr 63	right groins & seawall
		Mar 70	right groins & seawall
		Apr 73	right groins & seawall

(Continued)

(Sheet 2 of 10)

Table A1 (Continued)

Inlet Number	Inlet Name	Date of Photo	Condition
7	Gargathy, VA	Nov 49	no structures
		Oct 57	
		Apr 62	
		Oct 66	
		Oct 69	
		Dec 72	
8	Metomkin, VA	May 49	no structures
		Nov 49	
		Mar 55	
		Nov 57	
		Oct 59	
		Mar 62	
		Oct 66	
		Jan 67	
		Oct 69	
9	Wachapreague, VA	Nov 49	no structures
		Oct 57	
		Oct 59	
		Apr 62	
		Oct 66	
		Feb 67	
10	Oregon, NC	Jan 45	no structures
		Dec 49	
		May 53	
		May 58	
		Aug 59	
		May 62	
		Apr 64	
		Mar 75	
11	Hatteras, NC	Jan 45	no structures
		May 53	
		Mar 55	
		Mar 56	
		May 58	
		Aug 59	
		May 62	
		Apr 68	

(Continued)

(Sheet 3 of 10)

Table A1 (Continued)

Inlet Number	Inlet Name	Date of Photo	Condition
12	Beaufort, NC	Jun 53	left & right groins
		May 58	
		Mar 62	
		May 64	
		Oct 65	
13	Bogue, NC	May 53	no structures
		May 58	
		Oct 58	
		Aug 59	
		Nov 6	
		Oct 70	
14	New Topsail, NC	Oct 58	no structures
		Aug 59	
		May 62	
		Mar 66	
		Apr 68	
15	Rich, NC	Nov 49	no structures
		Mar 56	
		May 58	
		Oct 58	
		Aug 59	
		Mar 61	
		Mar 62	
		Mar 66	
		Apr 68	
		May 70	
16	Carolina Beach, NC	Mar 56	no structures
		Aug 59	
		Nov 60	
		Mar 62	
		Oct 63	
		Mar 66	
		May 70	
		Feb 72	
17	Lockwoods Folly, NC	Nov 49	no structures
		Mar 56	no structures
		Aug 59	no structures
		Jan 61	no structures

(Continued)

(Sheet 4 of 10)

Table A1 (Continued)

Inlet Number	Inlet Name	Date of Photo	Condition
17	Lockwoods Folly, NC	Mar 62	no structures
	(Cont'd)	Dec 69	no structures
		Mar 70	no structures
18	Shallotte, NC	Apr 49	no structures
		Mar 56	
		Aug 59	
		Mar 61	
		Mar 62	
		Apr 62	
		Mar 66	
		Apr 68	
		Dec 69	
		Apr 70	
		Dec 70	↓
19	Tubbs, NC	Nov 49	no structures
		Mar 56	
		Mar 61	
		Apr 62	
		Apr 64	
		Mar 66	
		Apr 68	
		Dec 69	
		Dec 70	↓[1]
20	Little River, SC	Mar 38	no structures
		Dec 49	
		May 63	
		Apr 64	
		Feb 68	
		Dec 69	
		Mar 70	
		Dec 72	↓
21	Murrells, SC	Mar 52	no structures
		Apr 57	
		Dec 63	
		Mar 64	
		Dec 70	
		Mar 73	↓

(Continued)

[1] Tubbs Inlet was artificially closed and reopened between Dec 69 and Dec 70.

(Sheet 5 of 10)

Table A1 (Continued)

Inlet Number	Inlet Name	Date of Photo	Condition
22	North, SC	Dec 49	no structures
		Mar 52	
		Nov 54	
		Apr 57	
		Apr 62	
		Feb 63	
		Dec 63	
		Apr 68	
		Apr 70	
		Mar 73	
23	South Santee, SC	Nov 41	no structures
		Apr 57	
		Dec 63	
		Nov 67	
		Apr 68	
24	Price, SC	Nov 41	no structures
		Mar 49	
		Mar 53	
		Oct 59	
		Oct 63	
		Apr 68	
25	Capers, SC	Mar 49	no structures
		Nov 54	
		Mar 57	
		Oct 59	
		Oct 63	
26	Dewees, SC	Nov 41	no structures
		Mar 49	
		May 54	
		Nov 54	
		Mar 57	
		Oct 59	
		Oct 63	
27	Lighthouse, SC	Apr 49	no structures
		Mar 53	
		Oct 59	
		Nov 63	
		Apr 68	

(Continued)

Table A1 (Continued)

Inlet Number	Inlet Name	Date of Photo	Condition
28	Nassau North, FL	Apr 51	no structures
		Feb 57	no structures
		Nov 62	no structures
		Nov 70	no structures
29	Nassau South, FL	Apr 51	no structures
		Feb 57	no structures
		Nov 62	no structures
		Nov 70	no structures
30	Fort George, FL	Aug 43	no structures[1]
		Feb 47	
		Apr 49	
		Apr 51	
		Nov 53	
		Nov 55	
		May 58	
		Oct 60	
		Oct 61	
		Nov 70	↓
31	St. Augustine, FL	Feb 47	left jetty
		Apr 49	left jetty
		Apr 51	left jetty
		Oct 56	left jetty
32	Matanzas, FL	Apr 51	no structures
		Oct 56	
		Nov 62	
		Sep 64	
		Oct 67	
		Nov 73	↓
33	Ponce De Leon, FL	Apr 49	no structures
		Oct 50	
		Oct 56	
		Nov 64	
		Nov 67	↓

(Continued)

[1] Fort George Inlet is bounded to the right by the St. Johns River north jetty.

(Sheet 7 of 10)

Table A1 (Continued)

Inlet Number	Inlet Name	Date of Photo	Condition
34	Sebastian, FL	Mar 51	jetties[1]
		Nov 54	
		Apr 58	
		Nov 64	
		Nov 68	
35	Boca Raton, FL	Mar 45	no structures
		Mar 47	
		Aug 59	
		Oct 61	
		Mar 71	
36	Hillsboro, FL	Mar 47	no structures
		Nov 54	right jetty
		Mar 57	
		Aug 59	
		Oct 61	
		Mar 62	
		Mar 65	
		Nov 68	
		Apr 73	
37	Redfish, FL	May 52	no structures
		Oct 58	
		Nov 60	
		May 69	
		Feb 70	
38	Gasparilla, FL	Mar 51	no structures
		Dec 51	no structures
		Feb 68	no structures
		Feb 70	no structures
39	Stump, FL	Mar 51	no structures
		Feb 52	no structures
		Feb 68	no structures
		Feb 70	no structures
40	Midnight, FL	Apr 45	no structures
		Dec 47	
		Dec 57	
		Mar 61	
		Feb 71	

(Continued)

[1] Sebastian Inlet was artificially opened between 1945 and 1947.

(Sheet 8 of 10)

Table A1 (Continued)

Inlet Number	Inlet Name	Date of Photo	Condition
41	Big Sarasota, FL	Feb 48	left groins & seawall
		Mar 57	left groins & seawall
		Mar 61	left groins & seawall
		Dec 69	left groins & seawall
42	Longboat, FL	Nov 51	no structures
		Dec 57	
		Nov 60	
		Mar 62	
		May 63	
		Nov 69	
		Dec 70	
43	Pass A Grille S., FL	Apr 45	no structures
		Nov 51	no structures
		Mar 57	no structures
		Nov 69	no structures
44	Pass A Grille N., FL	Apr 45	no structures
		Nov 51	no structures
		Mar 57	no structures
		Nov 69	no structures
45	Clearwater, FL	Apr 42	no structures
		Nov 51	
		Dec 54	
		Nov 60	
		Nov 70	
		Mar 71	
		Dec 71	
46	San Luis, TX	Jan 54	no structures
		Nov 56	
		Apr 57	
		Jan 62	
		May 64	
		Mar 68	
47	Bolinas, CA	? 39	right seawall
		Jan 42	right seawall
		Oct 47	right seawall
		Feb 56	right seawall

(Continued)

(Sheet 9 of 10)

Table A1 (Concluded)

Inlet Number	Inlet Name	Date of Photo	Condition
47	Bolinas, CA (Cont'd)	Sep 59	right seawall
		Jun 62	right seawall
		Dec 72	right seawall
		Sep 73	right seawall
48	Drakes, CA	Jun 52	no structures
		Nov 57	
		Jun 65	
		May 70	
		Apr 73	
		Apr 74	↓
49	Siuslaw, OR	Apr 57	jetties
		Jun 62	
		May 63	
		May 67	
		Sep 73	↓
50	Siletz, OR	Jul 39	no structures
		Oct 52	no structures
		Jan 71	no structures
		Feb 76	no structures
51	Netarts, OR	Jul 53	no structures
		Sep 58	no structures
		Aug 71	no structures
		Jul 73	no structures

(Sheet 10 of 10)

APPENDIX B: STABILITY INDICES FOR STUDIED INLETS

Appendix B presents a listing of stability indices (position, orientation, width, and length) through time for all inlets studied.

Table B1
Summary of Stability Indices

Month	Year	Position ft	Orientation ft	Width ft	Length ft
		Moriches Inlet			
8	1944	0	0	1367	1708
9	1947	-2229	512	500	1254
4	1954	-1423	158	667	825
3	1955	-269	300	783	1530
3	1957	-170	328	583	1432
5	1961	250	458	783	2050
3	1962	-540	63	400	1634
6	1963	530	160	833	2336
3	1966	-898	45	800	2303
10	1969	-218	555	733	3367
5	1970	-594	143	667	3205
3	1971	843	275	1000	3154
		Fire Island Inlet			
5	1955	0	0	1766	6310
4	1957	-831	487	2000	7376
1	1961	625	1482	2320	7131
3	1962	-97	680	2100	5323
10	1963	-1223	697	2000	7851
5	1964	-392	320	2050	8083
2	1965	820	183	2733	7642
2	1966	-438	343	2800	8036
5	1970	3824	2032	2000	4325
		Brigantine Inlet			
3	1940	0	0	4500	6174
4	1950	-372	619	5480	6401
4	1954	1272	827	5000	5783
1	1962	331	605	4200	5960
7	1963	1379	1305	2691	5180
6	1968	-932	520	1540	5909
		Corson Inlet			
2	1940	0	0	1916	3315
11	1949	-1201	605	933	4020
4	1950	-47	173	2430	3634

(Continued)

(Sheet 1 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
			Corson Inlet		
3	1951	-530	366	2533	4722
10	1952	890	729	1391	4170
6	1953	-157	502	1583	3728
4	1954	-601	223	1000	4592
3	1955	450	302	1433	3570
6	1956	-245	216	1133	4313
11	1957	920	552	833	3539
4	1959	591	699	1075	3915
6	1960	-94	315	1291	3670
9	1961	-364	201	491	3084
6	1963	-512	332	1450	2898
5	1965	-446	194	2375	3466
5	1966	-225	145	2541	3780
9	1967	-725	465	2666	3613
4	1968	56	156	2500	3455
4	1969	550	241	2991	3364
3	1970	-320	120	2683	3836
2	1971	-214	1916	3315	3215
			Townsend Inlet		
4	1940	0	0	666	5763
8	1944	-378	646	866	6573
4	1950	-128	60	900	6518
3	1951	-45	202	940	6701
3	1955	568	1139	883	6672
6	1956	-496	818	783	5963
5	1961	402	334	885	5062
3	1962	-139	641	950	6697
5	1963	-812	113	833	7070
9	1967	657	425	783	6089
3	1970	628	787	1075	5215
4	1973	-756	1073	633	6449
			Hereford Inlet		
4	1940	0	0	4250	7880
8	1944	280	489	5133	9202
3	1951	-1170	285	7483	7707
4	1954	1628	341	2883	8820
3	1955	-365	329	3083	10113

(Continued)

(Sheet 2 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
			Hereford Inlet		
6	1956	-8	237	2500	10474
3	1962	-3083	829	1380	9339
4	1963	706	519	1600	8108
3	1970	-220	899	2250	7860
4	1973	383	893	2040	9902
			Gargathy Inlet		
11	1949	0	0	383	2613
10	1957	1853	117	916	1837
4	1962	495	643	400	2791
10	1966	-471	826	250	1803
10	1969	397	98	333	1784
12	1972	447	471	290	2485
			Metomkin Inlet		
5	1949	0	0	3500	6047
11	1949	-50	180	3250	5955
3	1955	54	238	3366	5619
11	1957	-37	825	3466	5420
10	1959	349	327	3750	5741
3	1962	-510	234	4016	5390
10	1966	517	1355	4583	3597
1	1967	-466	821	4410	5148
10	1969	-541	765	4666	5309
			Wachapreague Inlet		
11	1949	0	0	2833	9007
10	1957	-509	363	2850	9155
10	1959	170	444	2541	8992
4	1962	-259	129	2416	9605
10	1966	571	419	2033	9291
2	1967	1146	561	1674	10363
			Oregon Inlet		
1	1945	0	0	4666	5535
12	1949	-489	702	2600	6840
5	1953	282	1097	2750	7203

(Continued)

(Sheet 3 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
			Oregon Inlet		
5	1958	-658	1116	3630	6293
8	1959	162	621	5208	6788
5	1962	518	99	6650	6546
4	1964	-270	483	6541	6561
3	1975	2613	1341	1666	8730
			Hatteras Inlet		
1	1945	0	0	3500	10415
5	1953	26	777	4833	8159
3	1955	49	491	3666	7766
3	1956	325	395	3716	8998
5	1958	-553	86	2900	8747
8	1959	-2979	1898	8729	6314
5	1962	201	1113	8683	4790
4	1968	-1129	194	8166	6495
			Beaufort Inlet		
6	1953	0	0	6983	12125
5	1958	85	398	3979	11115
3	1962	-715	471	4240	9256
5	1964	-218	542	3975	8200
10	1965	1012	360	4666	7676
			Bogue Inlet		
5	1953	0	0	5300	2808
5	1958	-555	446	2708	3985
10	1958	-151	80	3150	4179
8	1959	299	55	2833	4559
11	1960	-166	167	3400	4469
10	1970	1587	584	3800	3682
			New Topsail Inlet		
10	1958	0	0	1050	3249
8	1959	-1652	846	1458	2651
5	1962	675	584	1033	3665
3	1966	362	438	900	3801
4	1968	-198	151	833	3489

(Continued)

(Sheet 4 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
			Rich Inlet		
11	1949	0	0	1866	4339
3	1956	976	639	2933	4343
5	1958	912	310	3333	4059
10	1958	667	1355	3180	2936
8	1959	424	78	1395	3139
3	1961	223	200	1616	3747
3	1962	-435	30	2030	3560
3	1966	-826	562	1750	4693
4	1968	28	191	1733	4180
5	1970	-660	18	1266	4249
			Carolina Beach Inlet		
3	1956	0	0	433	1956
8	1959	-73	994	333	4050
11	1960	-294	595	383	3286
3	1962	-141	233	366	3949
10	1963	3	183	633	4097
3	1966	174	369	650	3[illegible]22
5	1970	-98	547	250	4137
2	1972	285	186	666	4616
			Lockwoods Folly Inlet		
11	1949	0	0	1333	4663
3	1956	-4	308	750	4804
8	1959	-711	597	1354	4281
1	1961	230	447	817	4284
3	1962	-219	547	800	3617
12	1969	194	628	1667	3757
3	1970	349	263	1333	4248
			Shallotte Inlet		
4	1949	0	0	583	4127
3	1956	-686	150	750	4112
8	1959	73	259	729	4385
3	1961	1328	733	950	3133
3	1962	27	353	1220	3475
4	1962	-95	113	1217	3789
3	1966	903	702	750	3885
4	1968	805	313	1067	4473

(Continued)

(Sheet 5 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
		Shallotte Inlet			
12	1969	353	323	1050	5547
4	1970	153	51	1067	5478
12	1970	-145	41	1400	5661
		Tubbs Inlet			
11	1949	0	0	833	2787
3	1956	-17	720	998	2806
3	1961	-1083	242	433	3324
4	1962	29	453	900	4498
4	1964	-1172	809	500	3253
3	1966	-953	22[illegible]	633	4030
4	1968	538	302	700	3717
12	1969	-636	597	550	4675
12	1970	4552	1265	833	1319
		Little River Inlet			
3	1938	0	0	1183	4842
12	1949	2226	1232	2117	9916
5	1963	-2636	2104	3500	7082
4	1964	-1102	575	3625	4228
2	1968	-1041	191	4467	6148
12	1969	-978	573	4117	5925
3	1970	43	241	4367	6662
12	1972	2231	781	3833	5559
		Murrells South Inlet			
3	1952	0	0	4267	2313
4	1957	-485	584	1633	3588
12	1963	-476	333	1917	3008
3	1964	-434	279	1958	3723
12	1970	-2586	1003	2000	4122
3	1973	450	564	1867	4721
		Murrells North Inlet			
12	1949	0	0	1583	7060
3	1952	520	200	2050	6516
11	1954	-814	153	2380	6167

(Continued)

(Sheet 6 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
		Murrells North Inlet			
4	1957	237	293	2633	5665
4	1962	1451	857	3100	5888
2	1963	-665	361	2375	6239
12	1963	-47	199	2833	6021
4	1968	777	715	2233	5583
4	1970	-705	290	1933	6087
3	1973	758	468	2000	5931
		South Santee Inlet			
11	1941	0	0	1333	9918
4	1957	9514	1610	1750	6572
12	1963	-1146	680	1833	7888
11	1967	-507	663	2167	7601
4	1968	-114	276	2167	7926
		Price Inlet			
11	1941	0	0	1033	6529
3	1949	-185	1531	550	4812
3	1953	327	888	633	5358
10	1959	290	542	1083	4969
10	1963	-86	968	833	3991
4	1968	-1650	486	500	4392
		Capers Inlet			
[illegible]	1949	0	0	1200	6808
11	1954	-542	737	940	8502
3	1957	-239	476	933	8080
10	1959	541	326	1000	6913
10	1963	-516	197	800	8126
		Dewees Inlet			
11	1941	0	0	1450	6804
3	1949	-261	529	1633	7699
5	1954	392	748	1217	9249
11	1954	-13	767	1500	6932
3	1957	-1779	910	1300	10253
10	1959	845	466	1917	8360
10	1963	325	288	1417	8100

(Continued)

(Sheet 7 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
			Lighthouse Inlet		
4	1949	0	0	917	5208
3	1953	227	237	1417	5093
10	1959	435	343	1563	5975
11	1963	129	382	1667	6095
4	1968	-125	625	1000	5376
			Nassau North Inlet		
4	1951	0	0	5500	8154
2	1957	-2192	1590	5400	13980
11	1962	177	841	5200	15809
11	1970	-1092	2027	5300	10252
			Nassau South Inlet		
4	1951	0	0	5500	16277
2	1957	936	695	5400	16710
11	1962	1121	985	5200	17782
11	1970	-1013	1066	5300	14379
			Fort George Inlet		
8	1943	0	0	1583	4193
2	1947	648	109	1500	4790
4	1949	-290	83	1767	4775
4	1951	186	430	1760	4555
11	1953	-412	798	1967	2709
11	1955	-82	594	633	3917
5	1958	349	411	1521	4243
10	1960	290	724	2467	3846
10	1961	488	187	960	4506
11	1970	842	302	1267	4486
			St. Augustine Inlet		
2	1947	0	0	1420	6859
4	1949	344	185	1067	7002
4	1951	577	582	1000	8101
10	1956	-1785	1200	1367	5599

(Continued)

(Sheet 8 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
		Matanzas Inlet			
4	1951	0	0	1017	3977
10	1956	-222	261	817	3430
11	1962	-705	336	850	3180
9	1964	299	281	808	2699
10	1967	301	372	833	3703
11	1973	276	34	1275	3757
		Ponce De Leon Inlet			
4	1949	0	0	2583	4388
10	1950	-381	563	1950	5438
10	1956	107	364	2683	4596
11	1964	-638	493	2867	5119
10	1967	585	403	2733	4394
		Sebastian Inlet			
3	1951	0	0	267	1794
11	1954	-134	200	500	1788
4	1958	173	263	517	2543
11	1964	98	299	433	2136
11	1968	-118	94	433	1859
		Boca Raton Inlet			
3	1945	0	0	250	1214
3	1947	-33	78	217	1216
9	1959	-108	67	217	1319
10	1961	53	96	240	1100
3	1971	18	119	275	972
		Hillsboro Inlet			
3	1947	0	0	183	812
11	1954	-184	23	333	754
3	1957	220	120	233	996
8	1959	-260	181	367	1077
10	1961	188	237	240	1120
3	1962	-80	298	325	721
3	1965	-573	263	233	1196
11	1968	138	125	333	1571
4	1973	185	277	570	1048

(Continued)

(Sheet 9 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
			Redfish Pass		
5	1952	0	0	607	4420
10	1958	89	521	625	3841
11	1960	-424	327	708	4577
5	1969	203	229	517	4606
2	1970	66	184	566	4893
			Gasparilla Pass		
3	1951	0	0	1353	4166
12	1951	343	183	1167	4347
2	1968	685	435	1833	3954
2	1970	-281	198	1867	4354
			Stump Pass		
3	1951	0	0	700	2106
2	1952	-1061	49	817	2164
2	1968	-1547	556	483	2104
2	1970	-645	447	367	2684
			Midnight Pass		
4	1945	0	0	533	1847
12	1947	-86	137	780	2391
12	1957	-2025	625	300	2034
3	1961	578	346	250	1766
2	1971	155	296	600	2086
			Big Sarasota Pass		
2	1948	0	0	2700	9999
3	1957	865	582	2950	8285
3	1961	-581	117	3167	7708
12	1969	-579	836	3333	8819
			Longboat Pass		
11	1951	0	0	500	3285
12	1957	-205	609	583	4348
11	1960	62	323	630	3982
3	1962	-154	120	680	3777

(Continued)

(Sheet 10 of 12)

Table B1 (Continued)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
		Longboat Pass			
5	1963	150	123	750	4255
11	1969	-567	738	800	4781
12	1970	429	648	833	4520
		Pass A Grille South			
4	1945	0	0	1850	10881
11	1951	185	559	1717	11819
3	1957	-277	428	1667	10450
11	1969	1347	789	1760	9690
		Pass A Grille North			
4	1945	0	0	1850	8626
11	1951	296	79	1717	8987
3	1957	-257	492	1667	7551
11	1969	-672	1062	1760	9592
		Clearwater Pass			
4	1942	0	0	3017	6097
11	1951	-63	272	2383	6070
12	1954	-115	49	2240	5910
11	1960	69	402	1860	7331
11	1970	99	183	1200	6658
3	1971	-238	33	1200	6733
12	1971	-52	337	1050	5250
		San Luis Pass			
1	1954	0	0	2350	6708
11	1956	191	567	2950	7064
4	1957	-301	90	3033	6380
1	1962	-827	551	3502	6489
5	1964	-394	421	3833	5771
3	1968	270	100	3983	5186
		Bolinas Inlet			
1	1939	0	0	267	1083
1	1942	-256	360	317	1583
10	1947	732	636	433	1733

(Continued)

(Sheet 11 of 12)

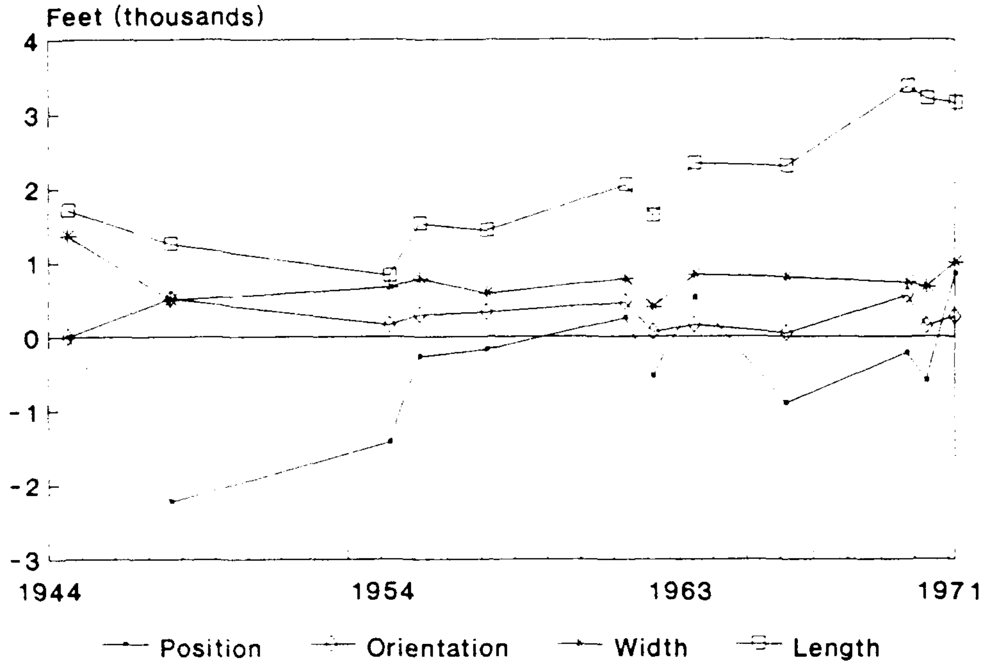
Table B1 (Concluded)

Month	Year	Position ft	Orientation ft	Width ft	Length ft
			Bolinas Inlet		
2	1956	-212	336	240	1450
9	1959	-145	110	242	1625
6	1962	-72	41	380	1760
12	1972	166	231	392	1625
9	1973	148	8	352	1787
			Drakes Inlet		
6	1952	0	0	420	2791
11	1957	874	344	1600	2465
6	1965	405	352	1000	2781
5	1970	-759	103	200	2939
4	1973	-542	49	1257	2980
4	1974	868	148	1250	2896
			Siuslaw Inlet		
4	1957	0	0	702	2167
6	1962	237	291	875	3000
5	1963	446	255	735	2025
5	1967	-189	284	750	2167
9	1973	194	413	688	1125
			Siletz Inlet		
7	1939	0	0	333	1417
10	1952	-404	185	367	2083
1	1971	450	186	453	1867
2	1976	-146	53	467	1917
			Netarts Inlet		
7	1953	0	0	869	6167
9	1958	-726	474	1050	6125
8	1971	606	227	1270	6085
7	1973	-459	578	1155	6188

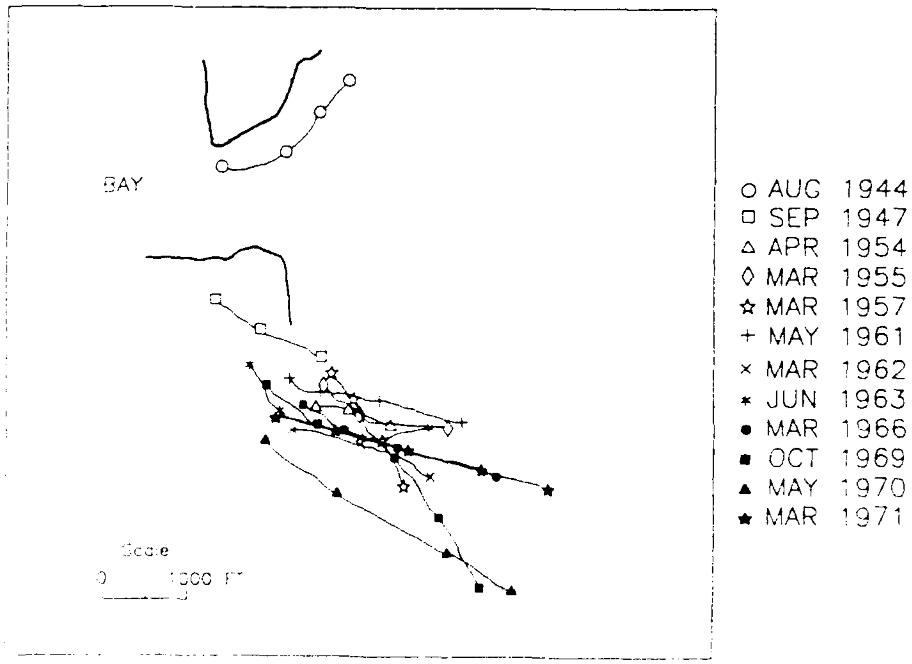
(Sheet 12 of 12)

APPENDIX C: TEMPORAL VARIATION IN CHANNEL PARAMETERS FOR STUDIED INLETS

Appendix C presents plots of the temporal variation in (a) channel position and orientation (relative to an initial condition), channel width and length, and (b) channel traces for all inlets studied.

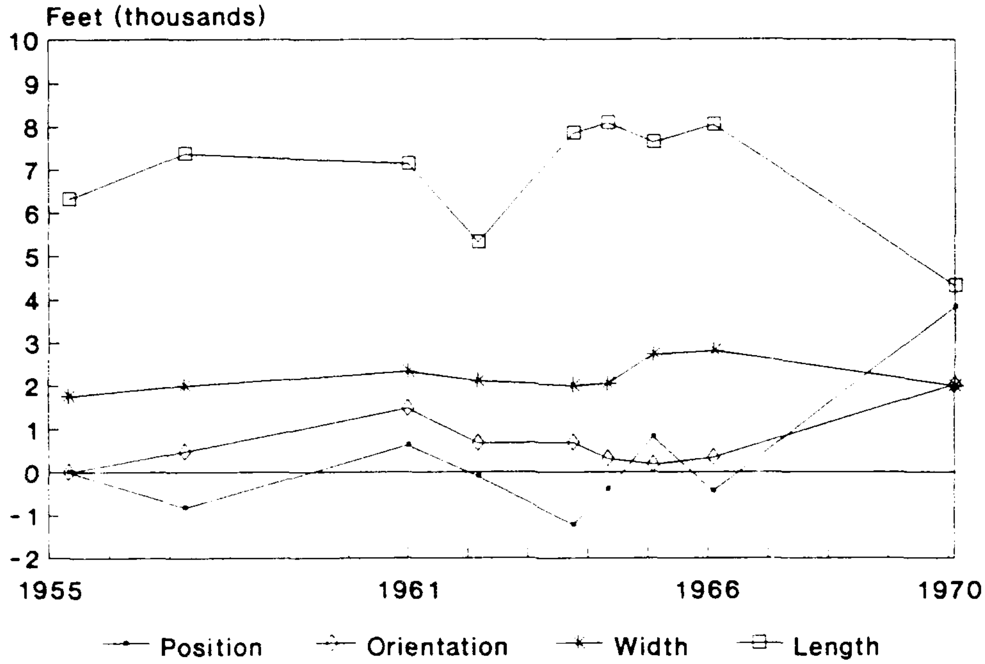


a.



b.

Figure C1. Moriches



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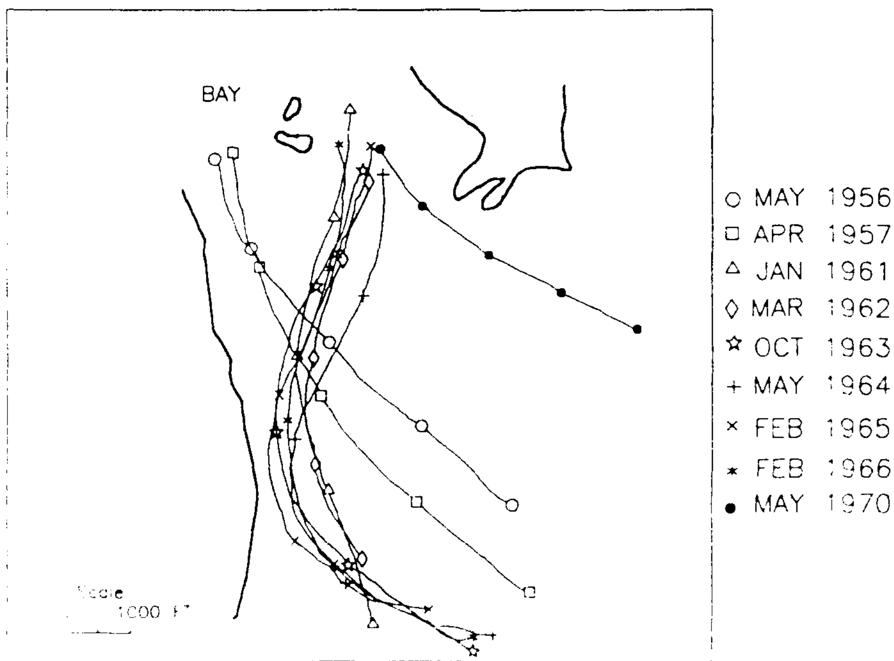
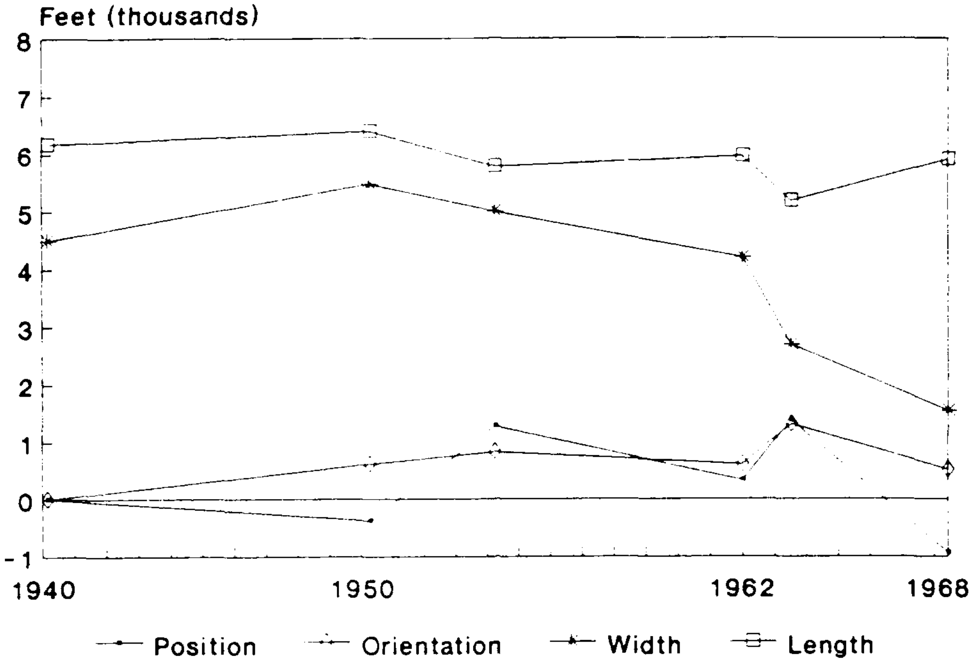


b.

Figure C2. Fire Island



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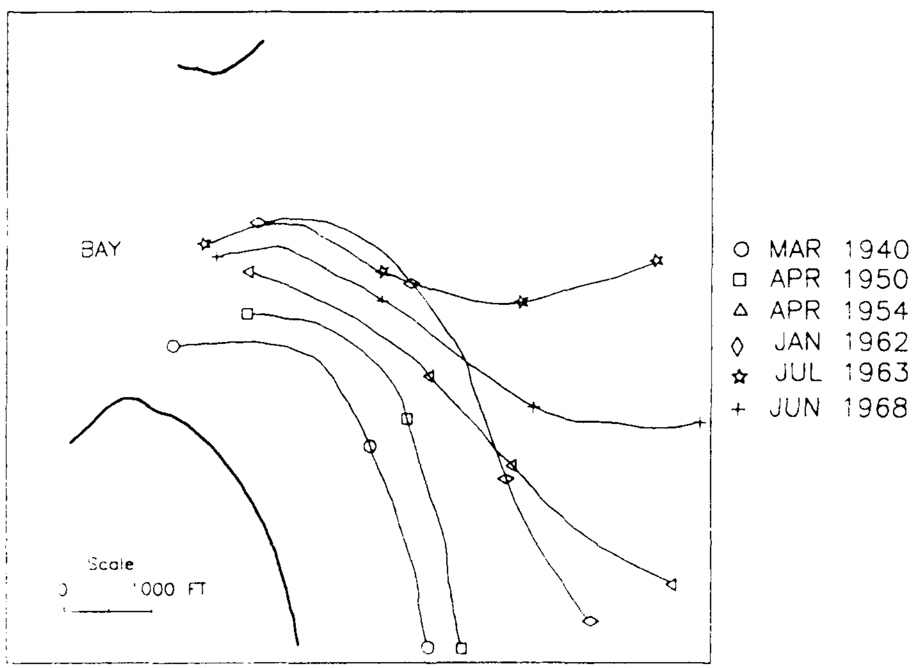
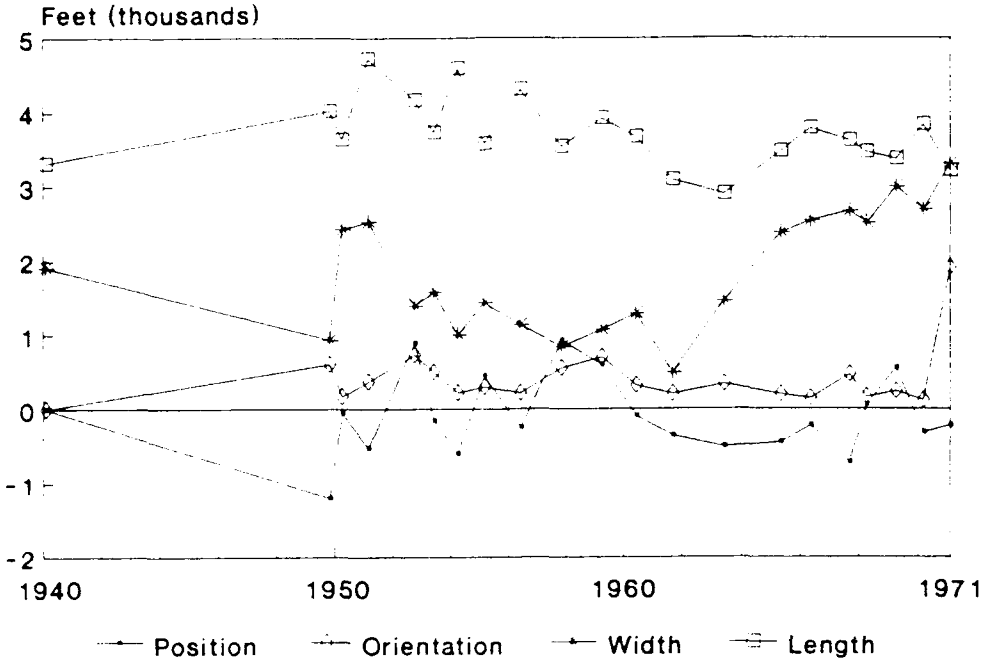


b.

Figure C3. Brigantine



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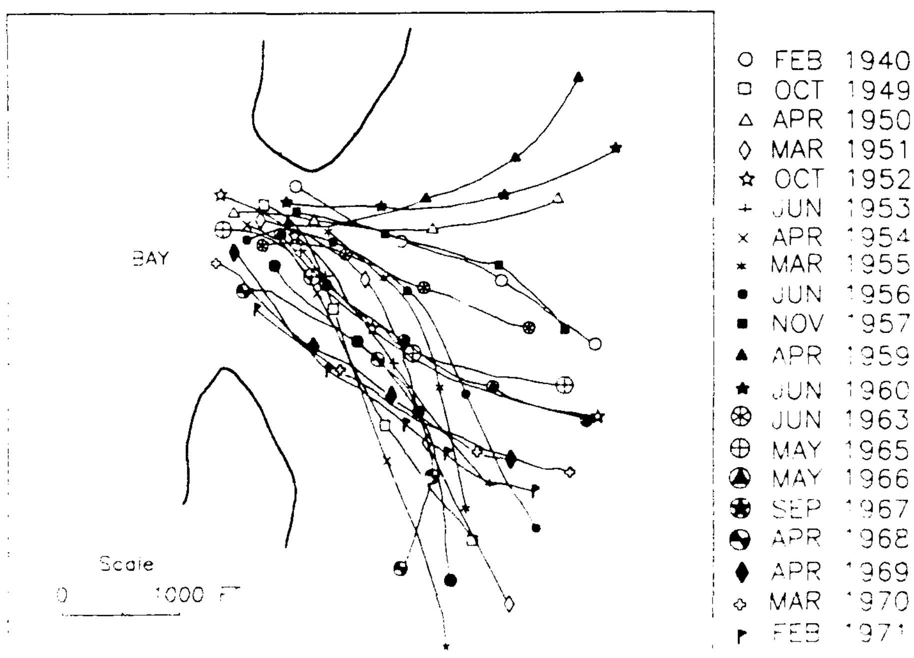
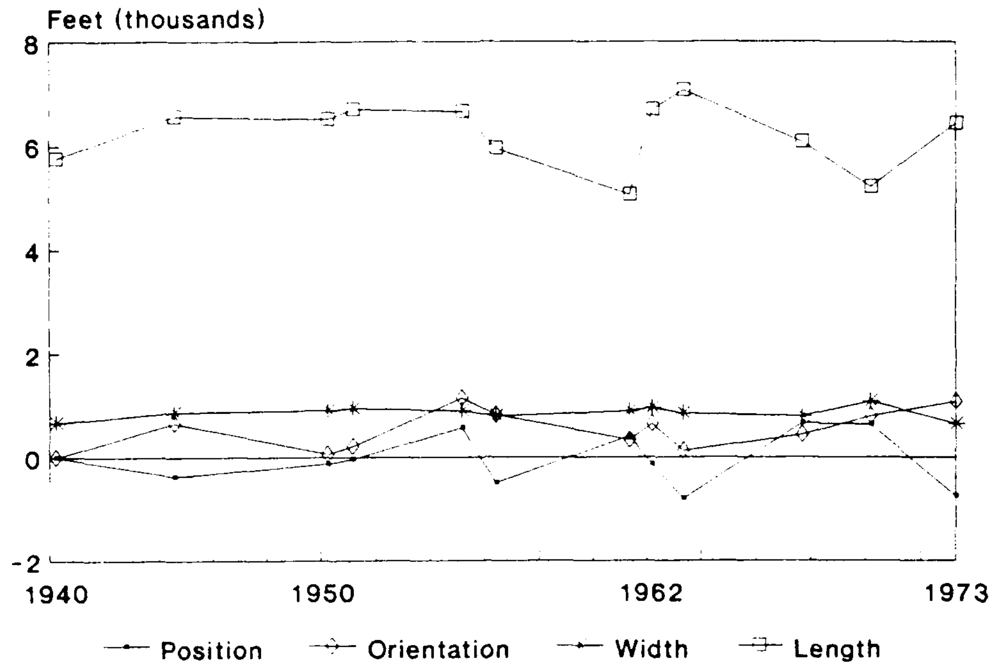


b.

Figure C4. Corson



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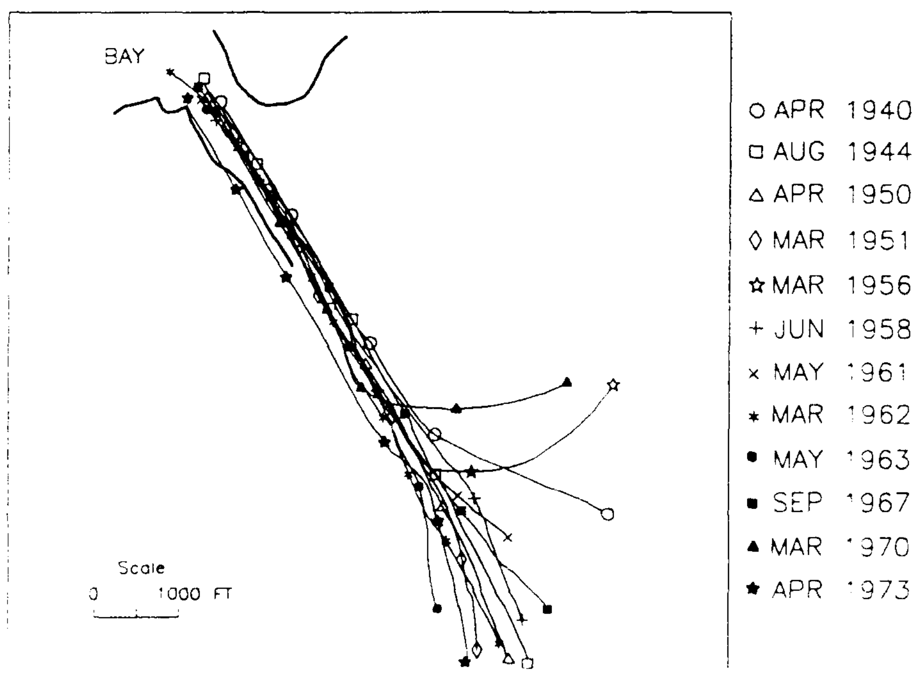
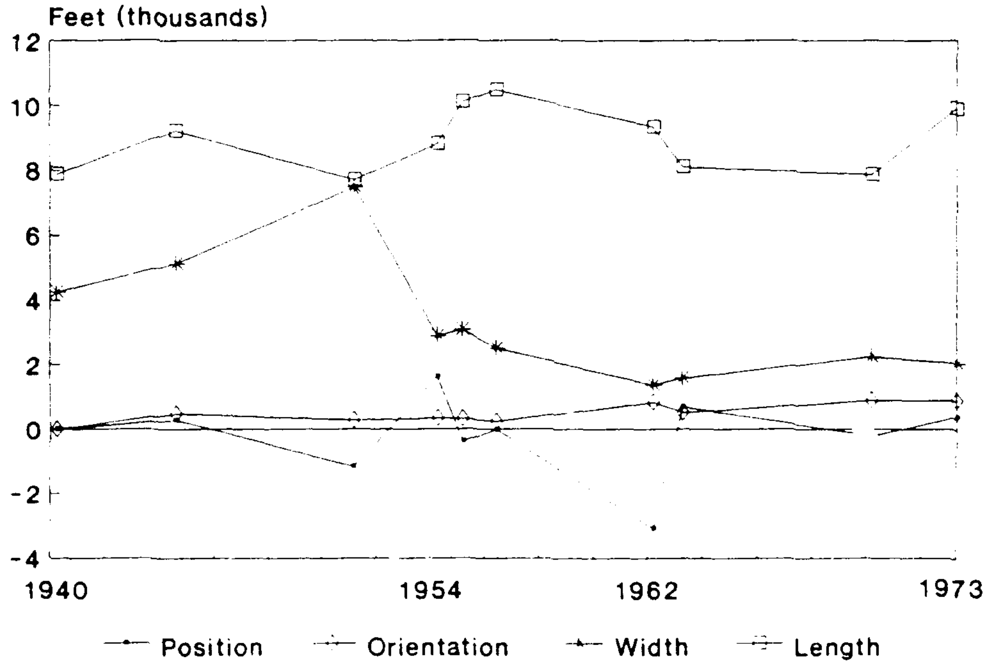


b.

Figure C5. Townsend



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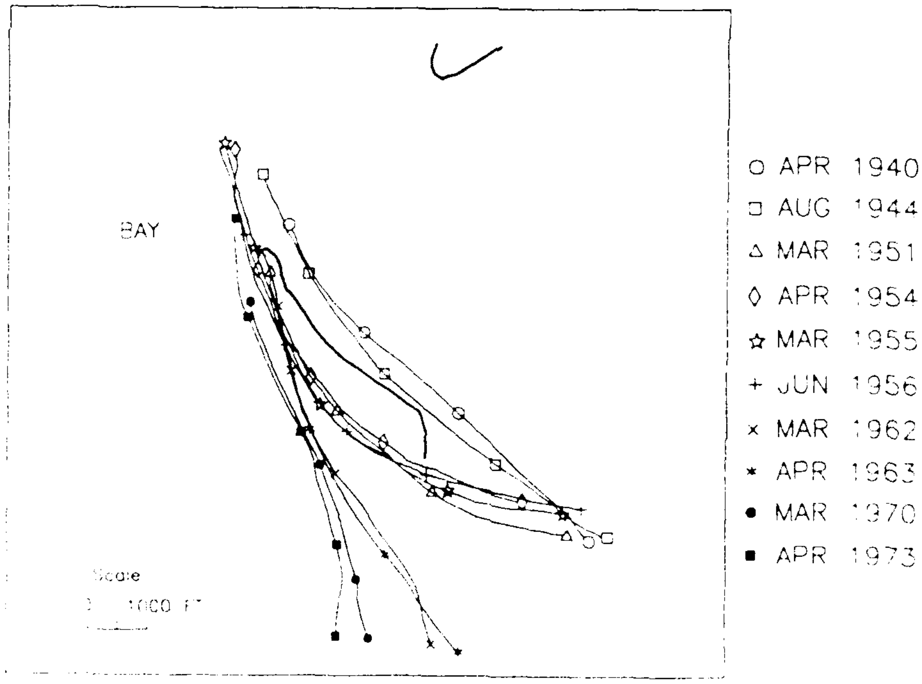
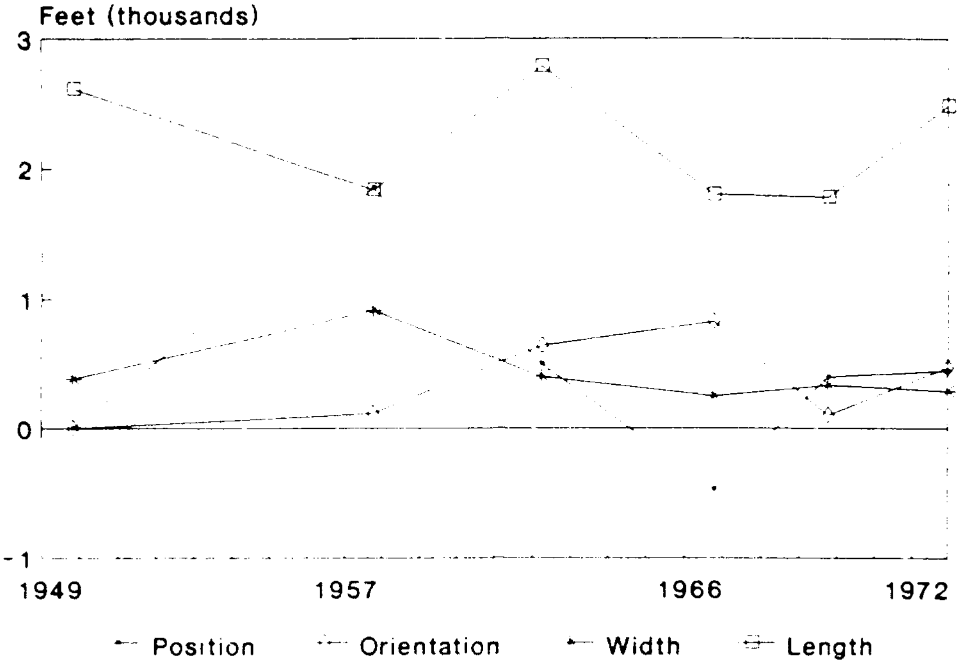


b.

Figure C6. Hereford



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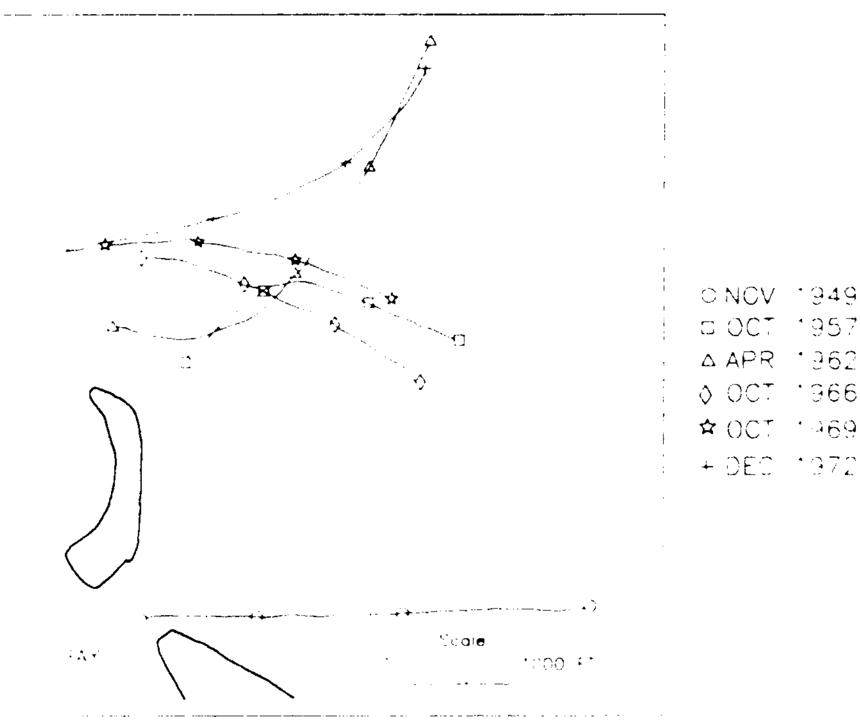
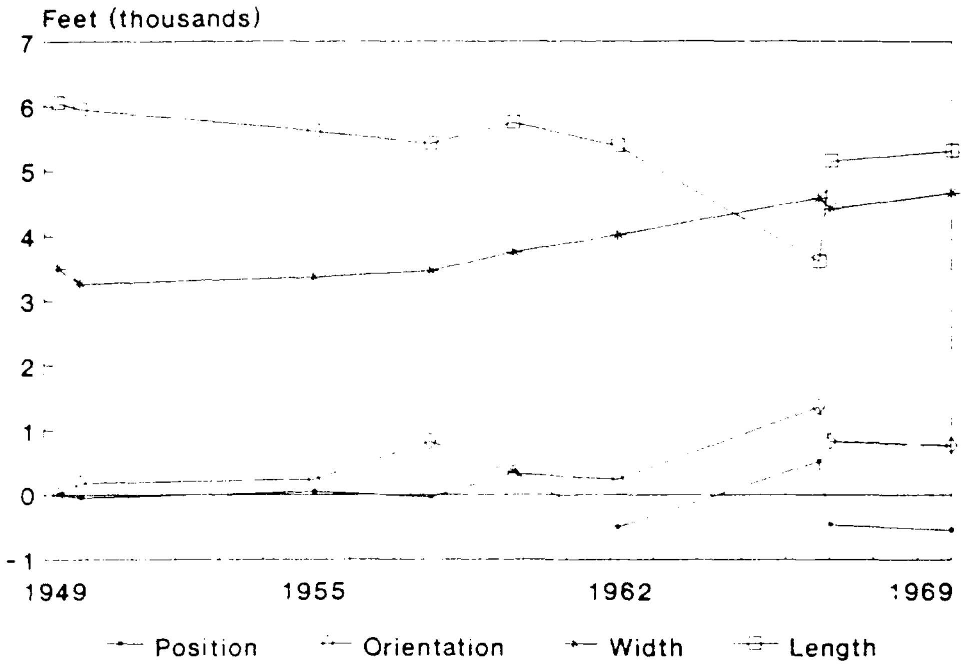


b.

Figure C7. Gargathy



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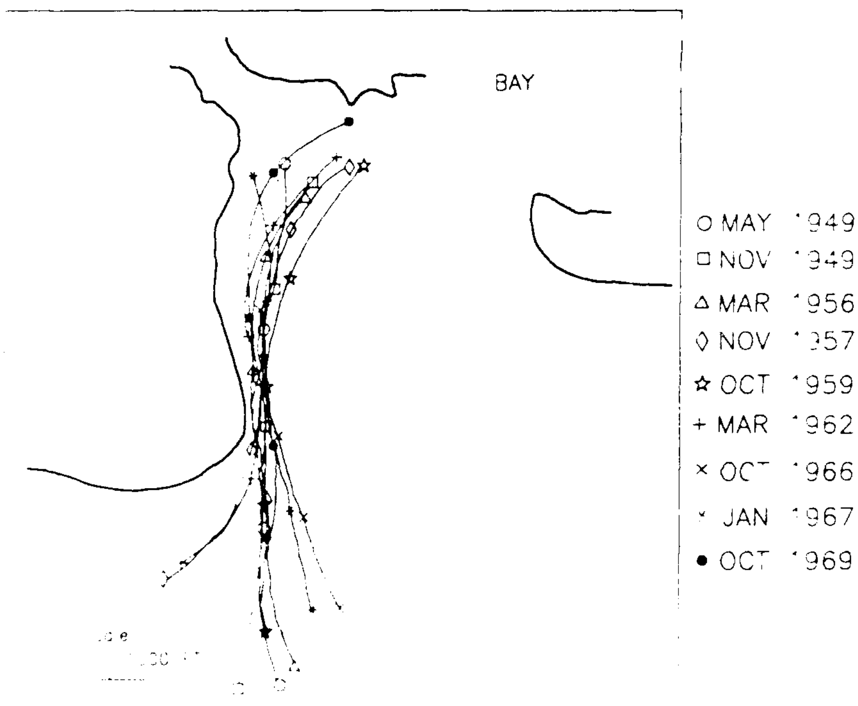
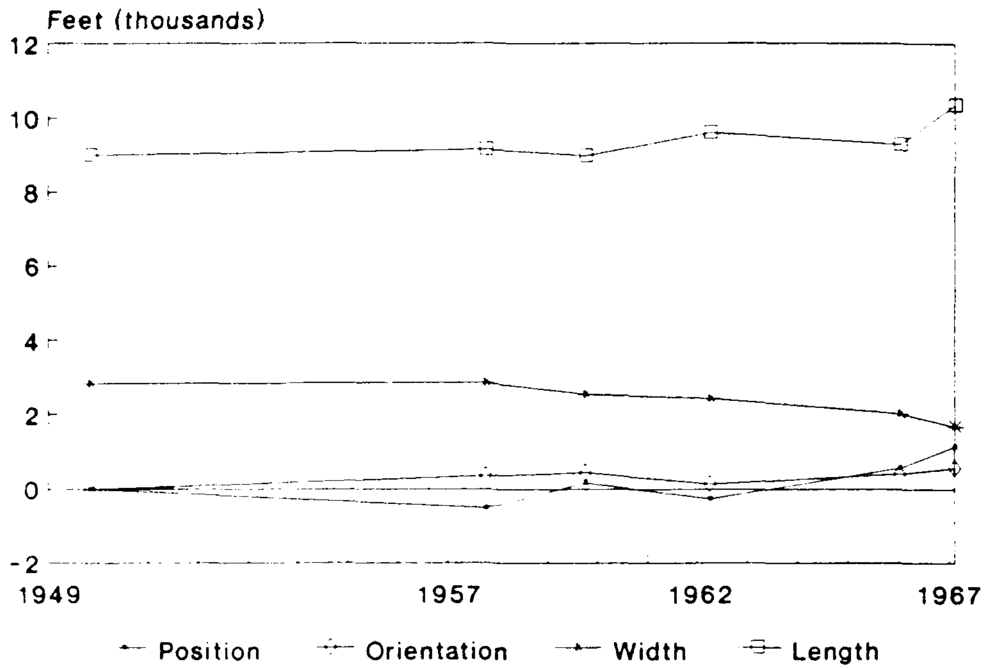


b.

Figure C8. Metomkin



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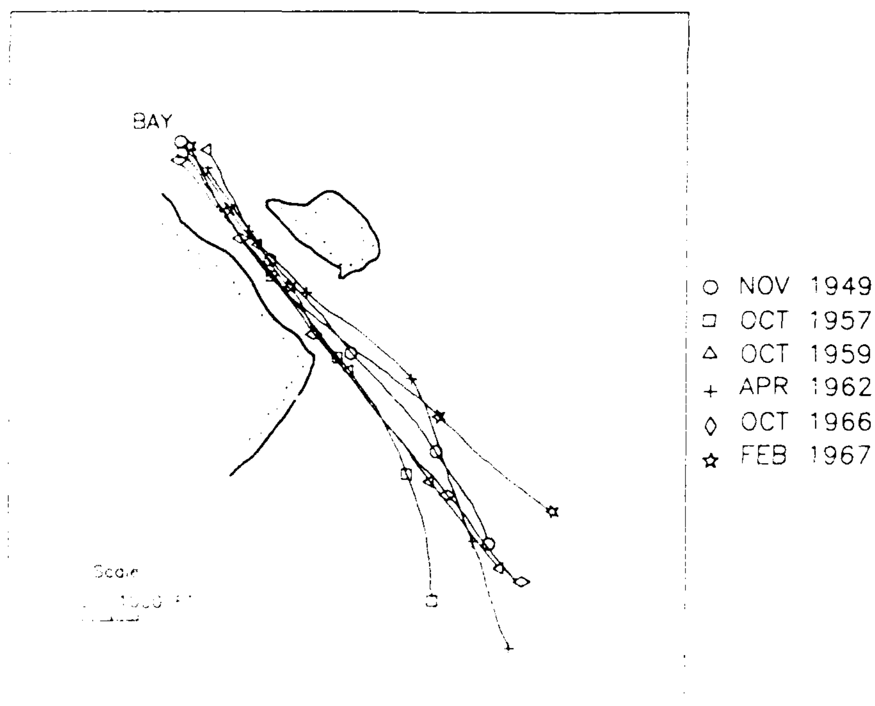
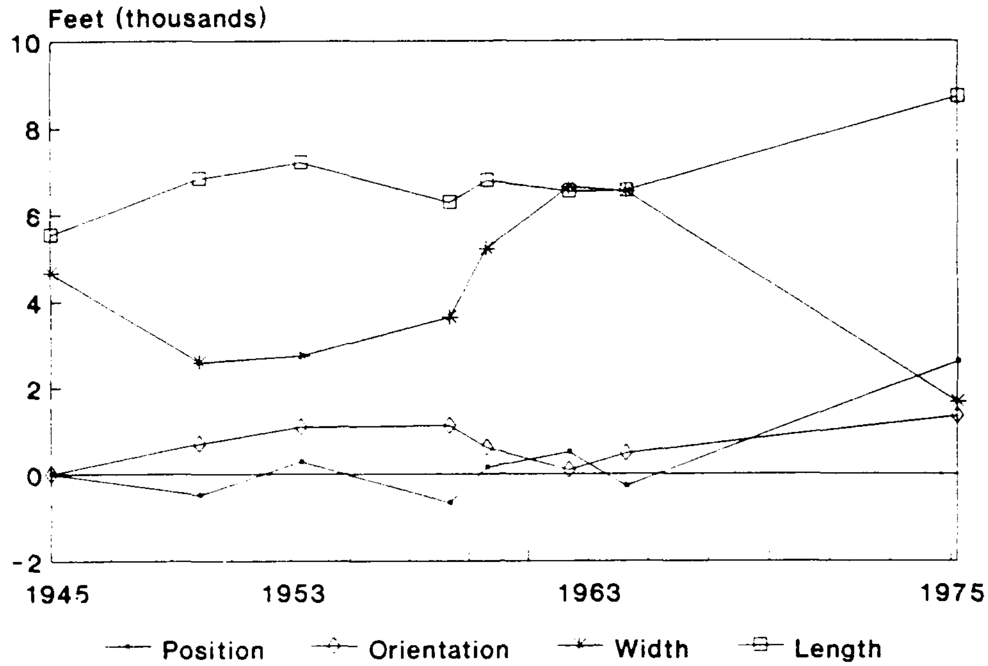


b.

Figure C9. Wachapreague



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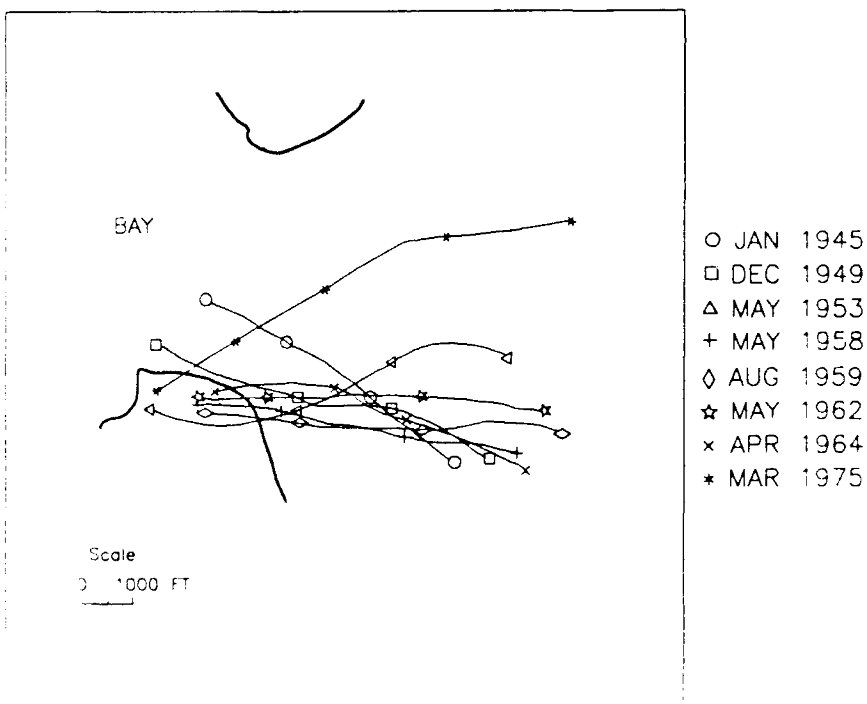
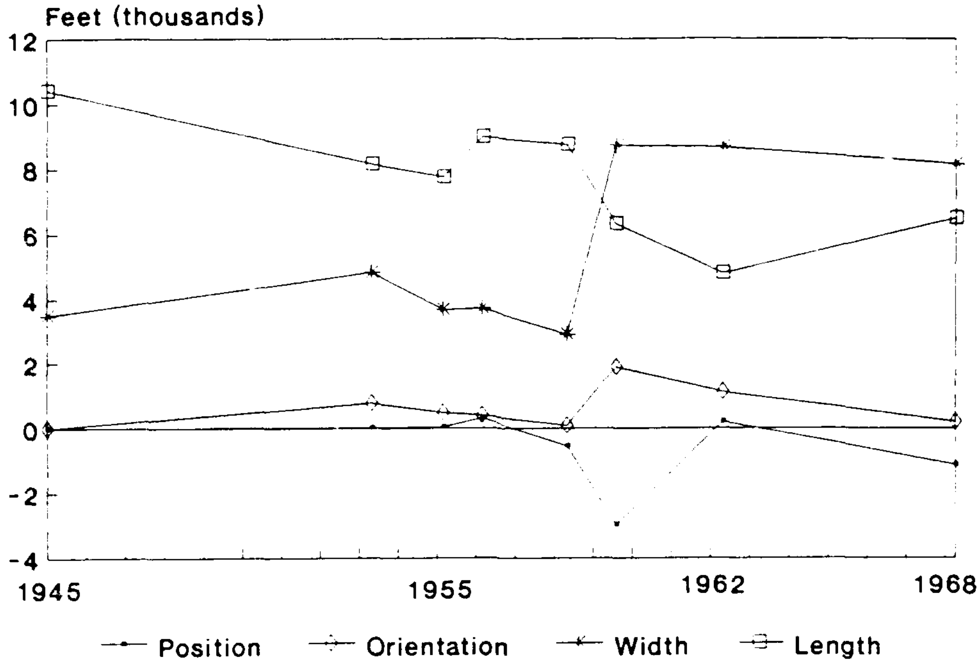


b.

Figure C10. Oregon



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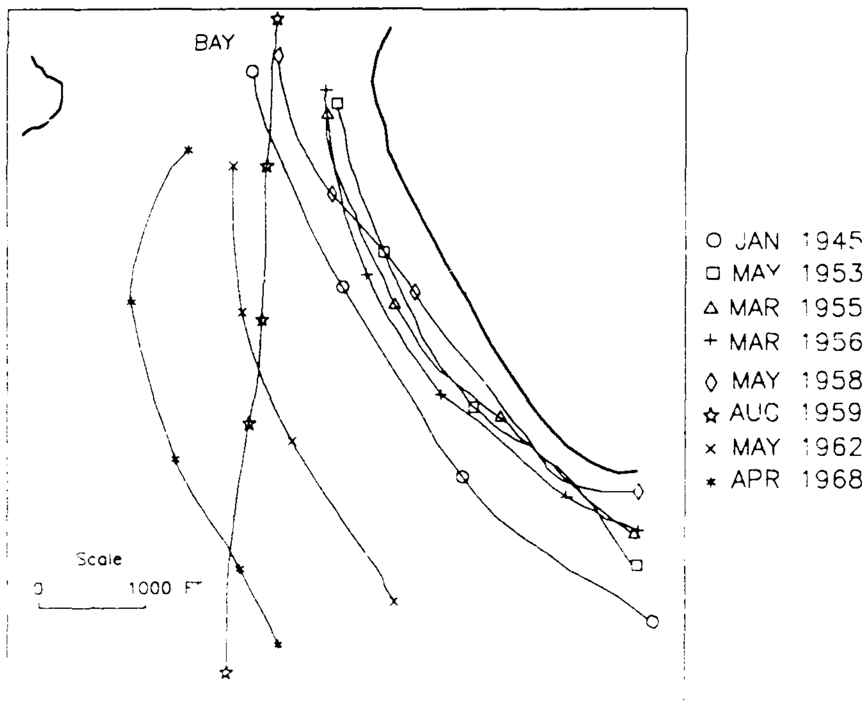
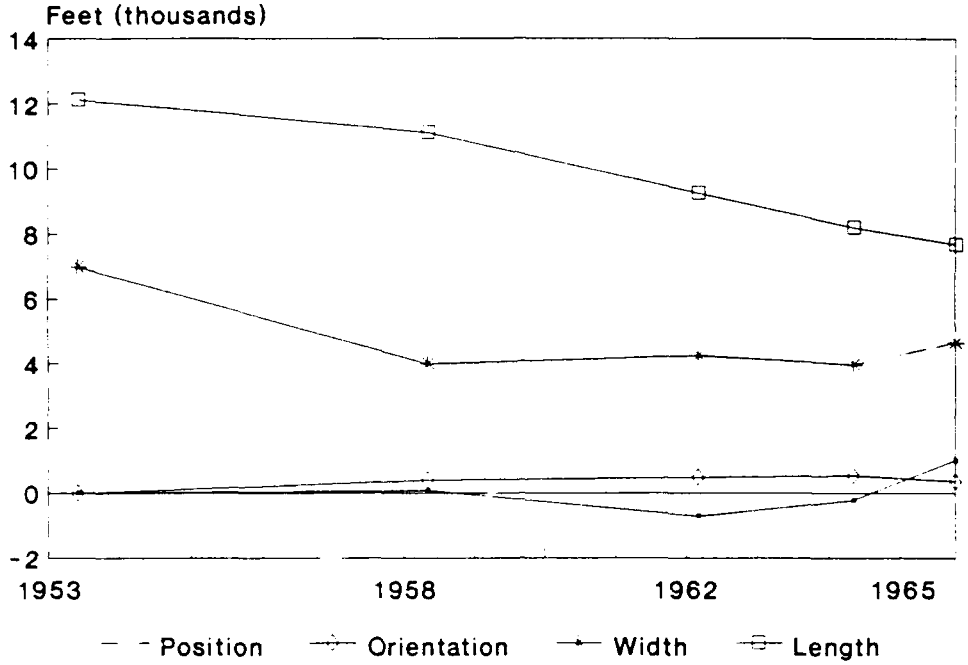


b.

Figure C11. Hatteras



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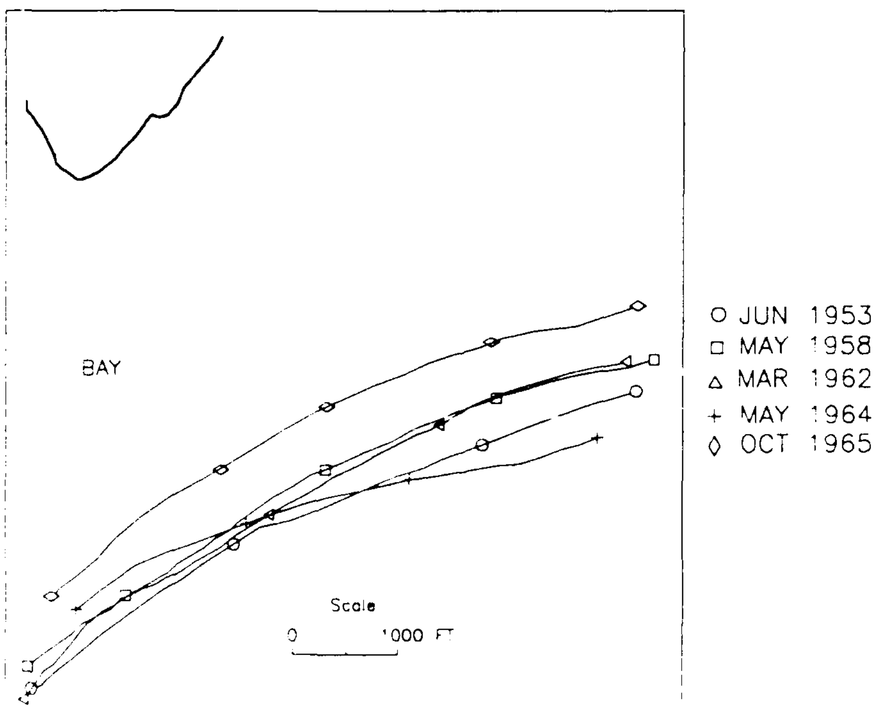

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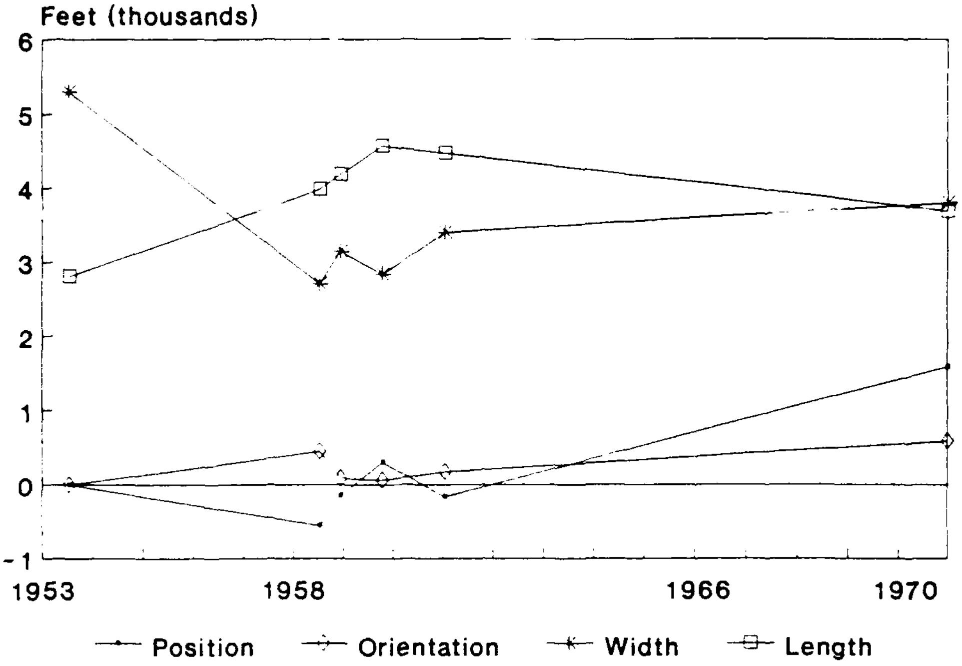
Figure C12. Beaufort



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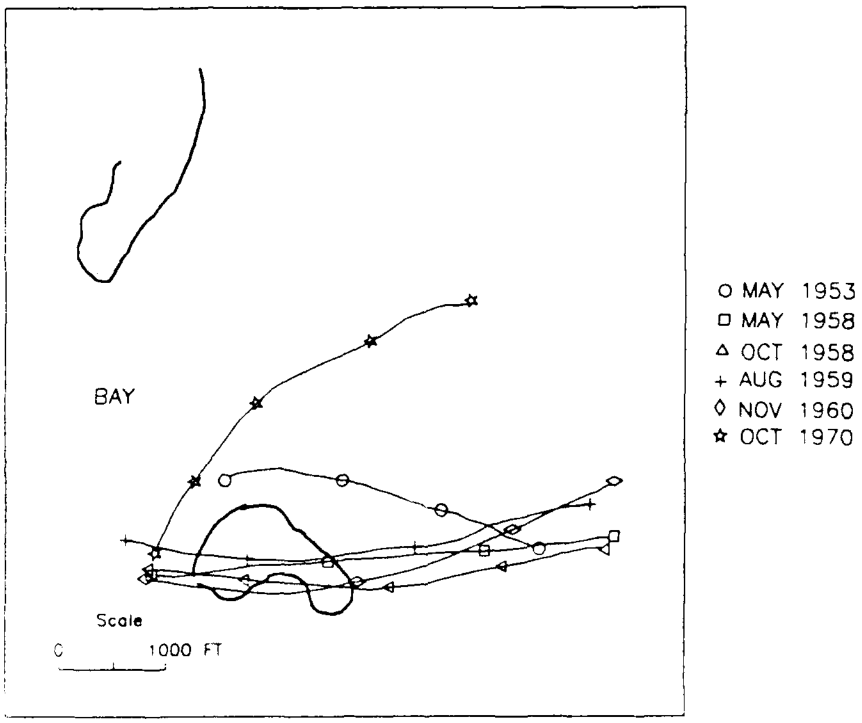

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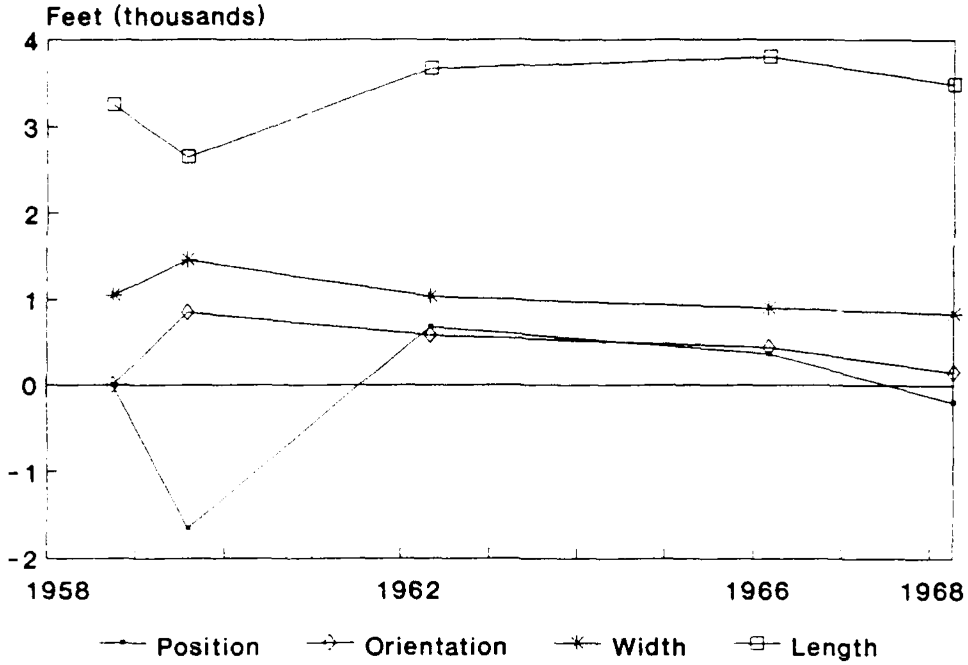
Figure C13 Bogue



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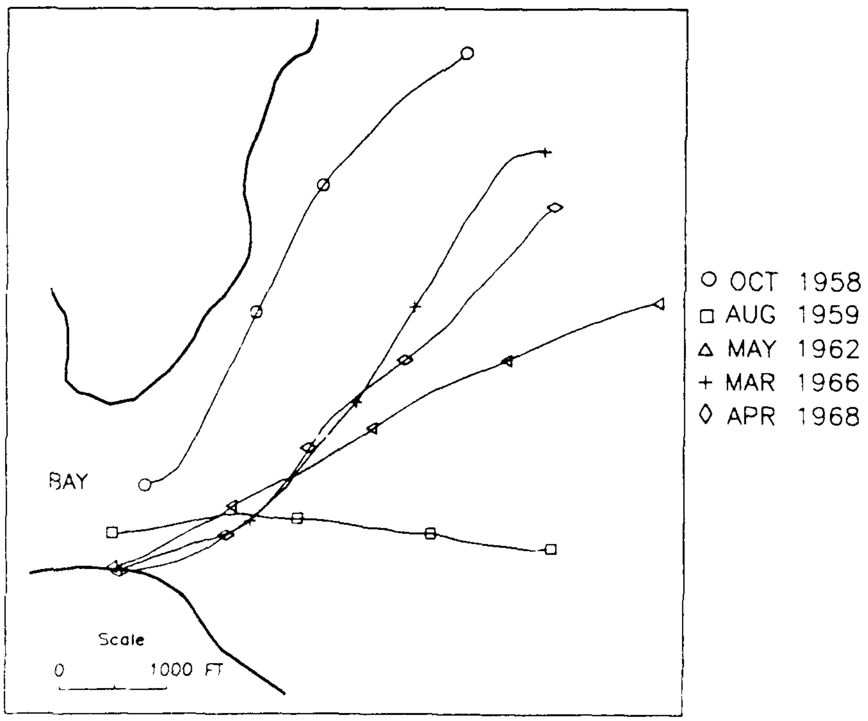

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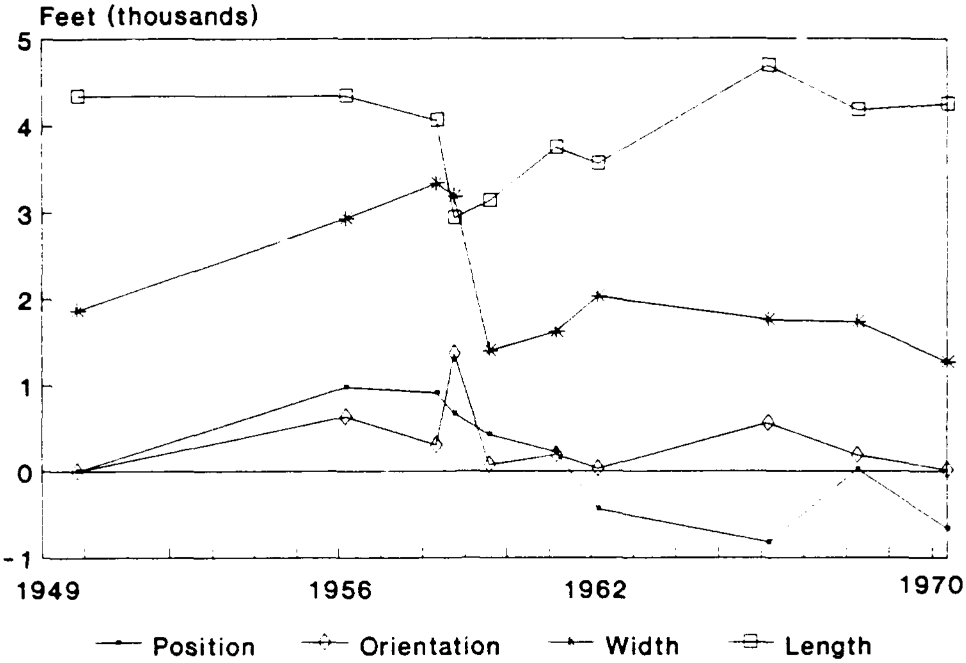
Figure C14. New Topsail



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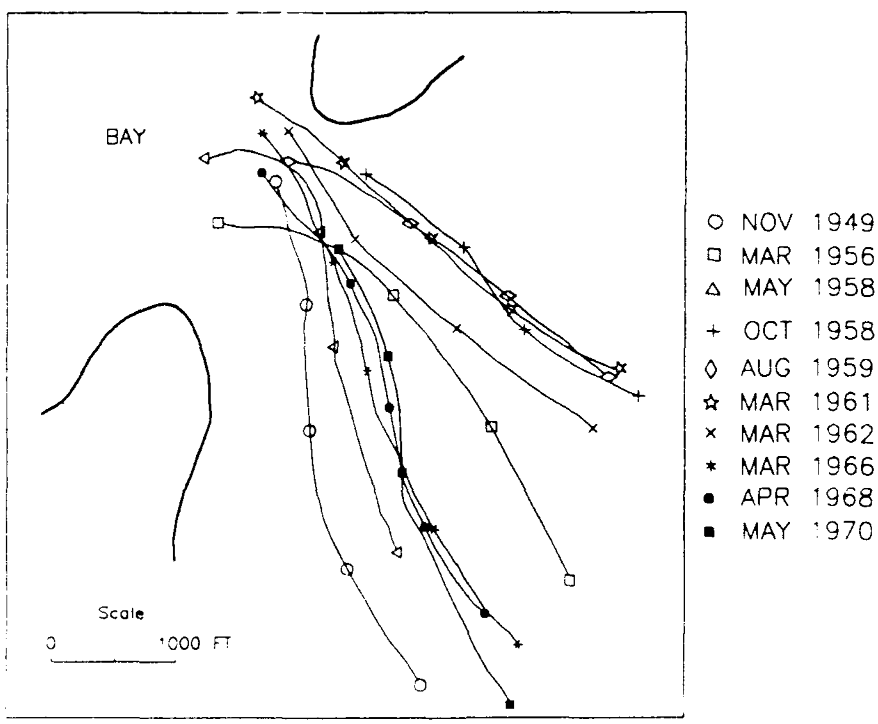

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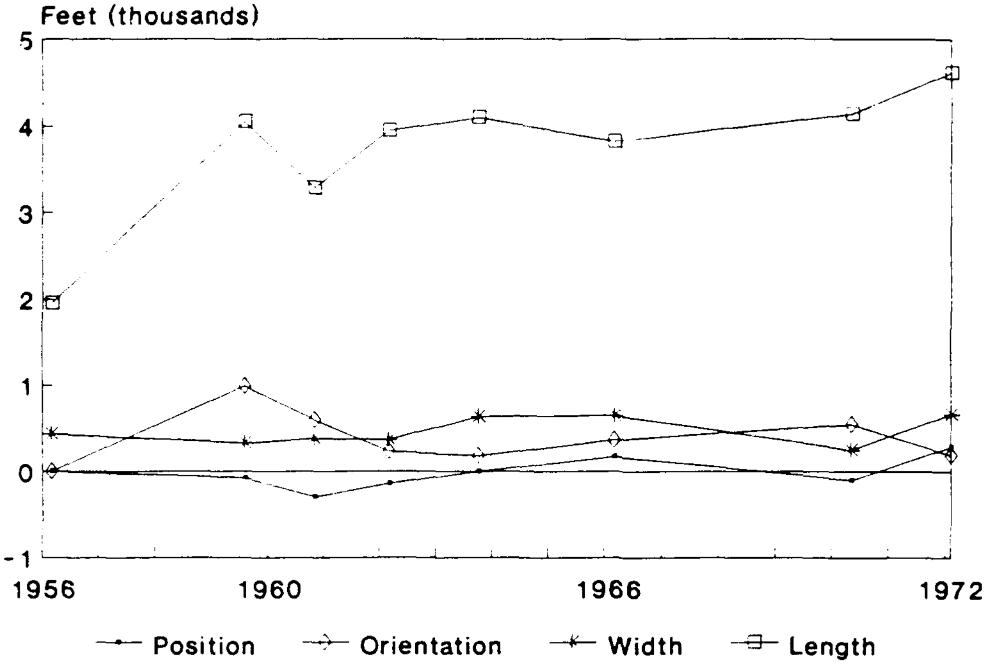
Figure C15. Rich



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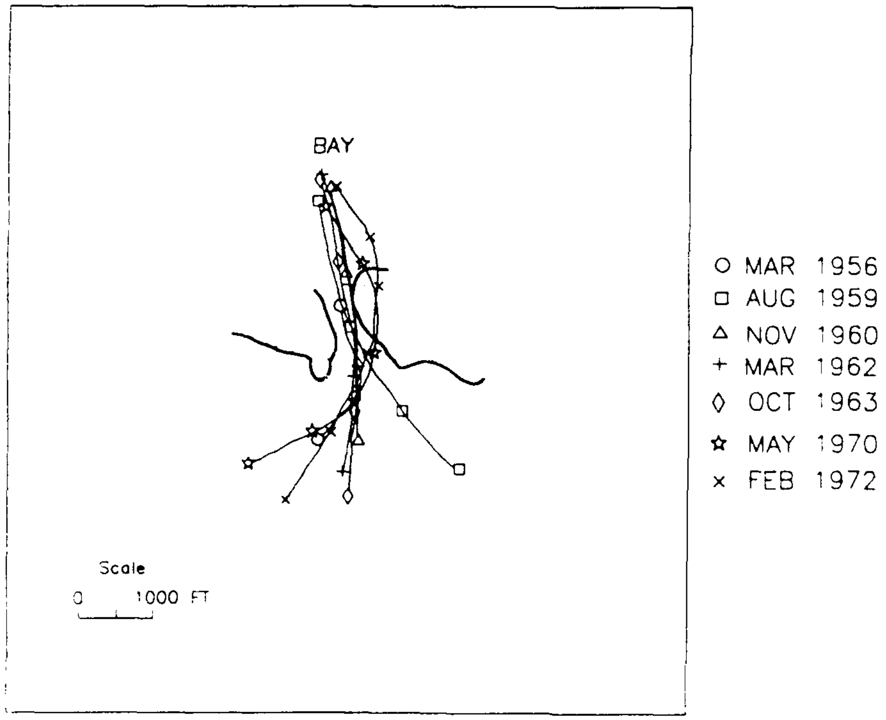

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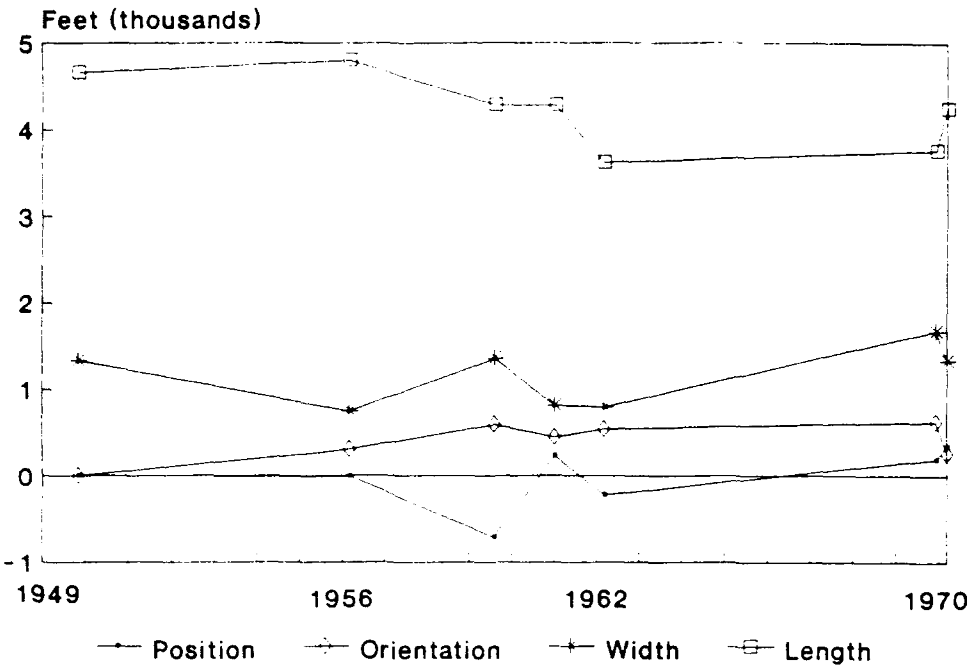
Figure C16. Carolina Beach



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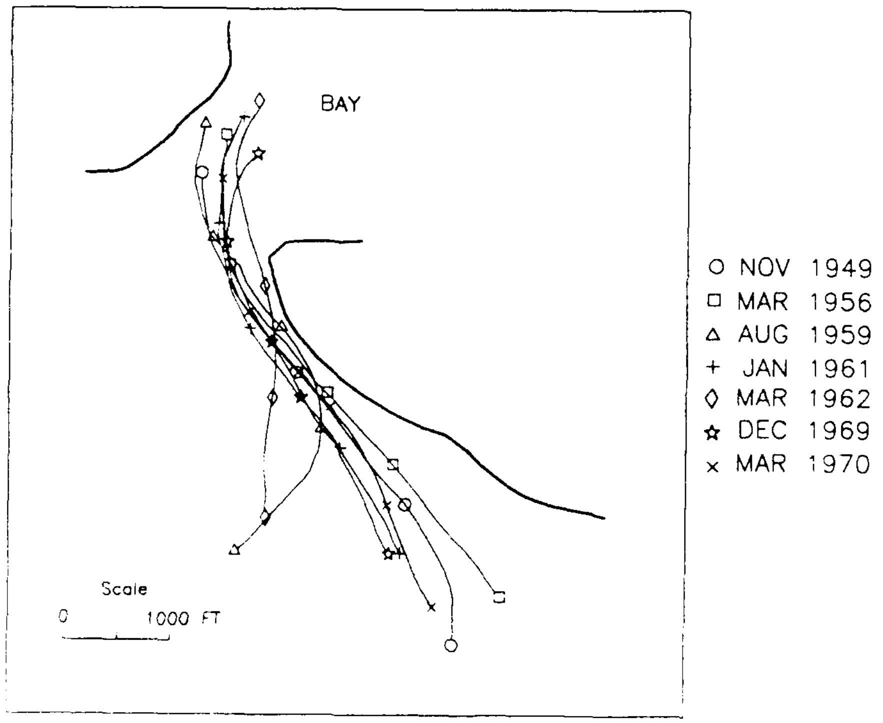

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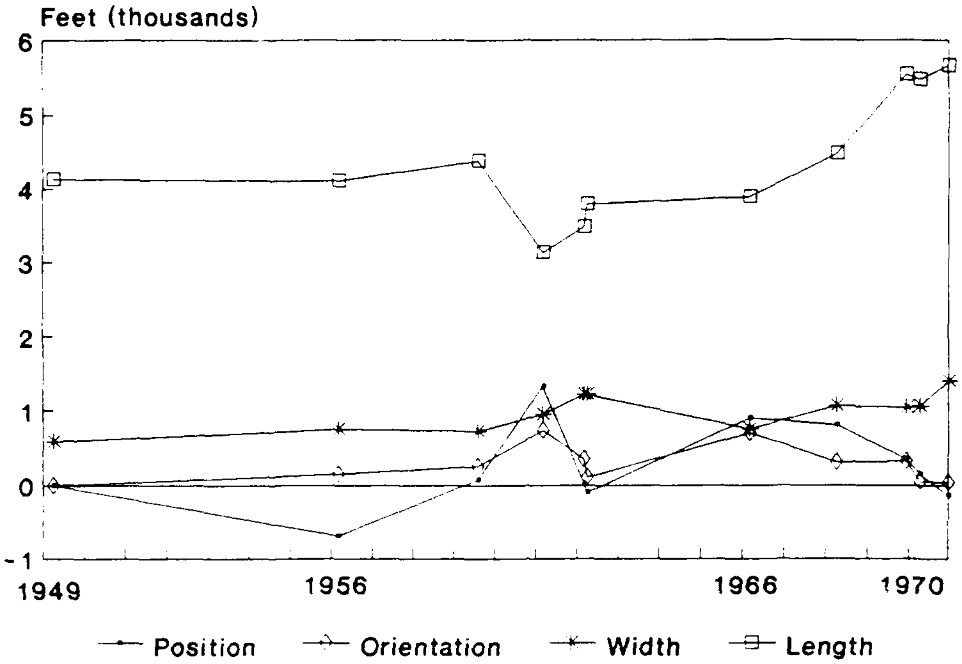
Figure C17. Lockwoods Folly



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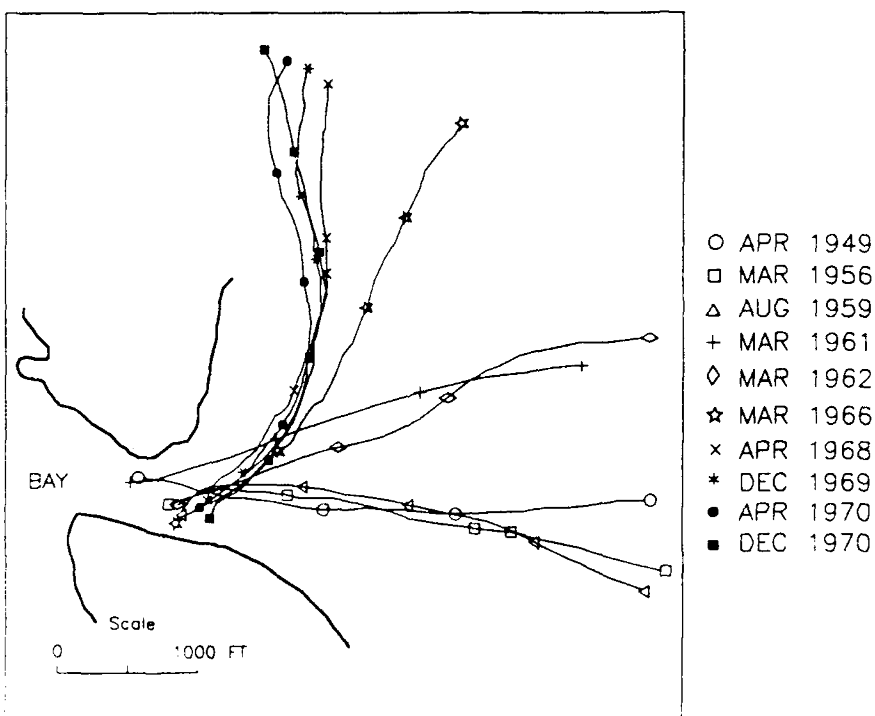

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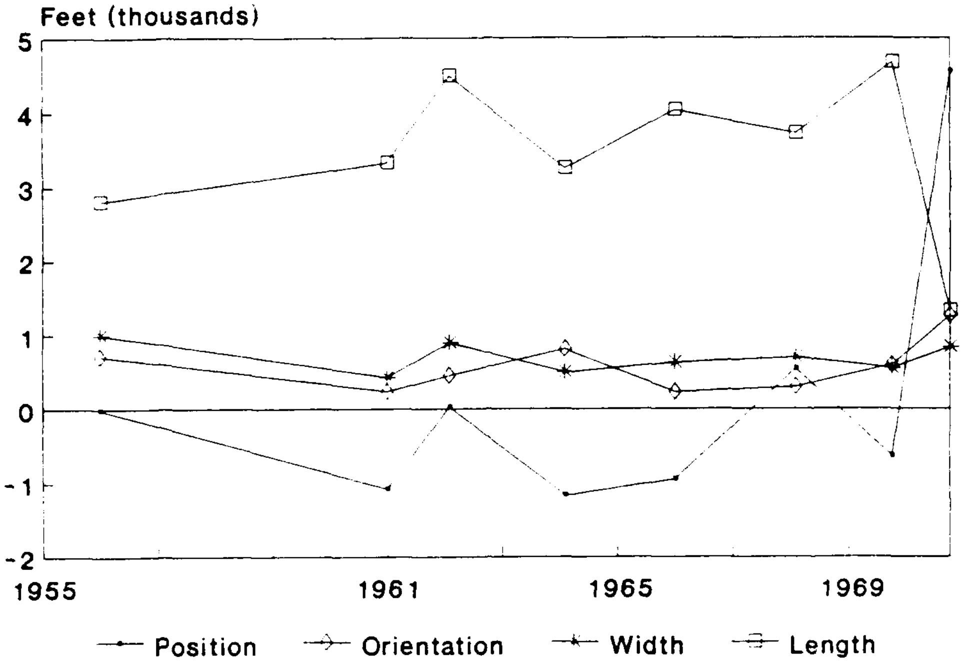
Figure C18. Shallotte



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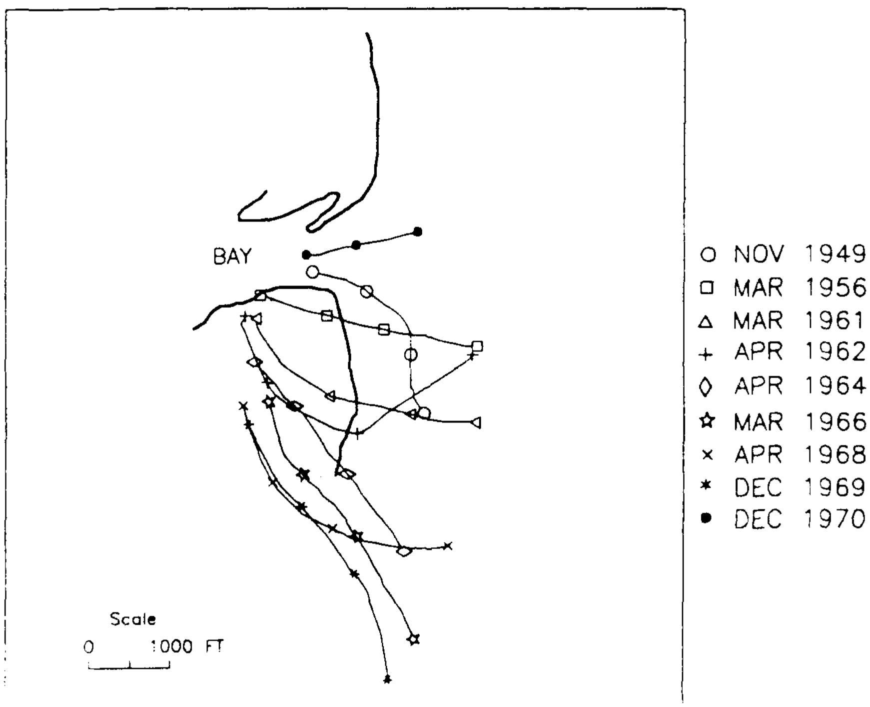

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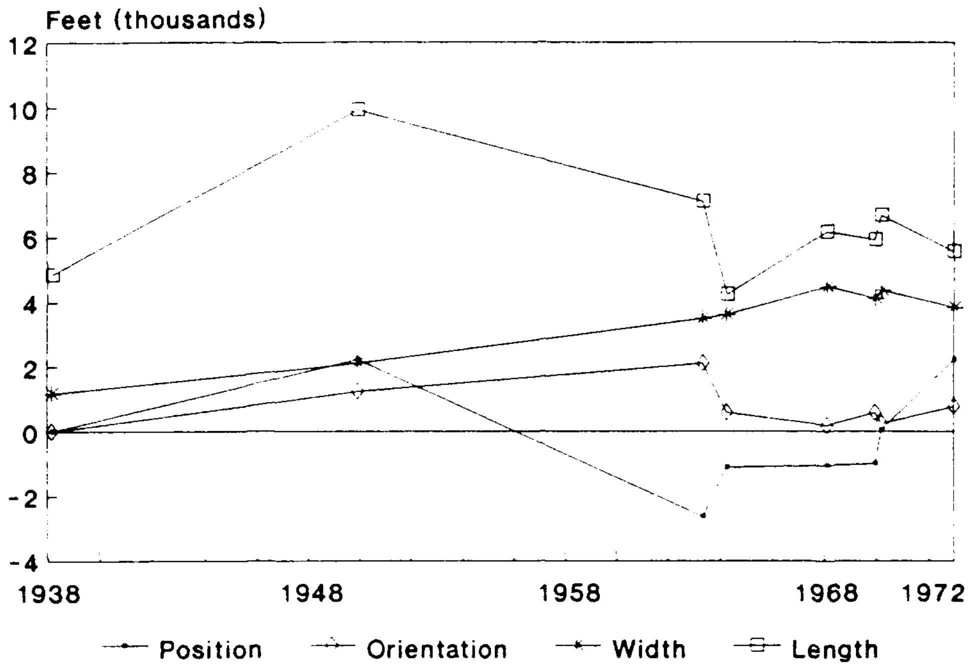
Figure C19. Tubbs



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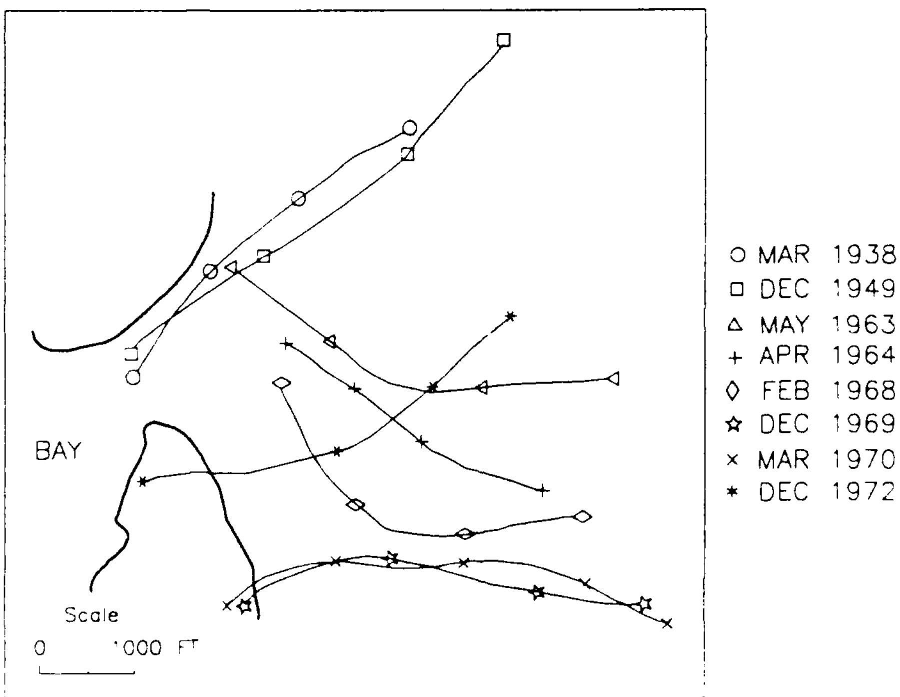

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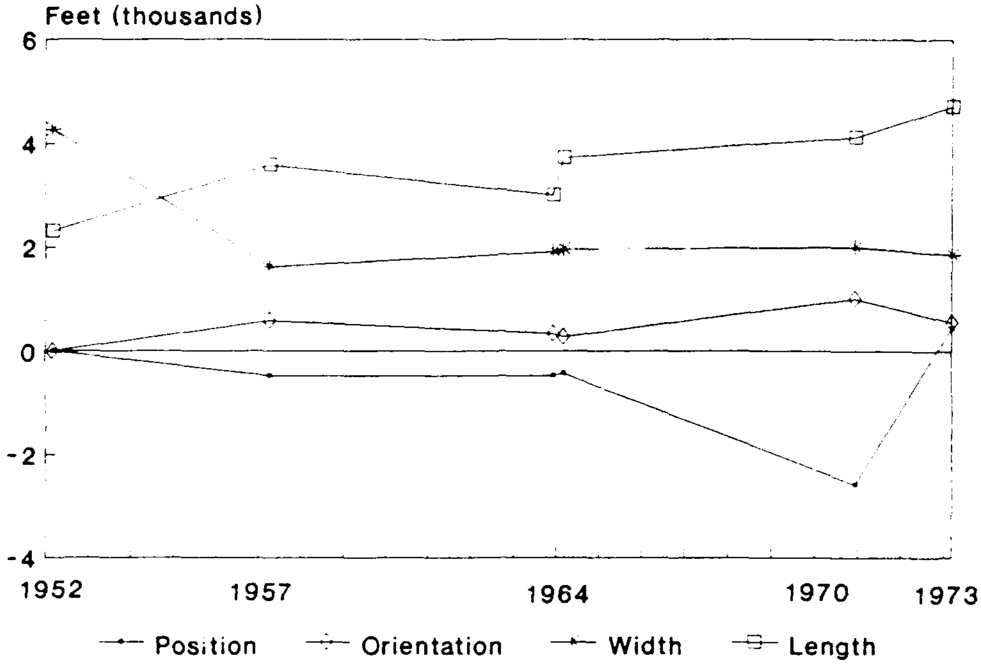
Figure C20. Little River



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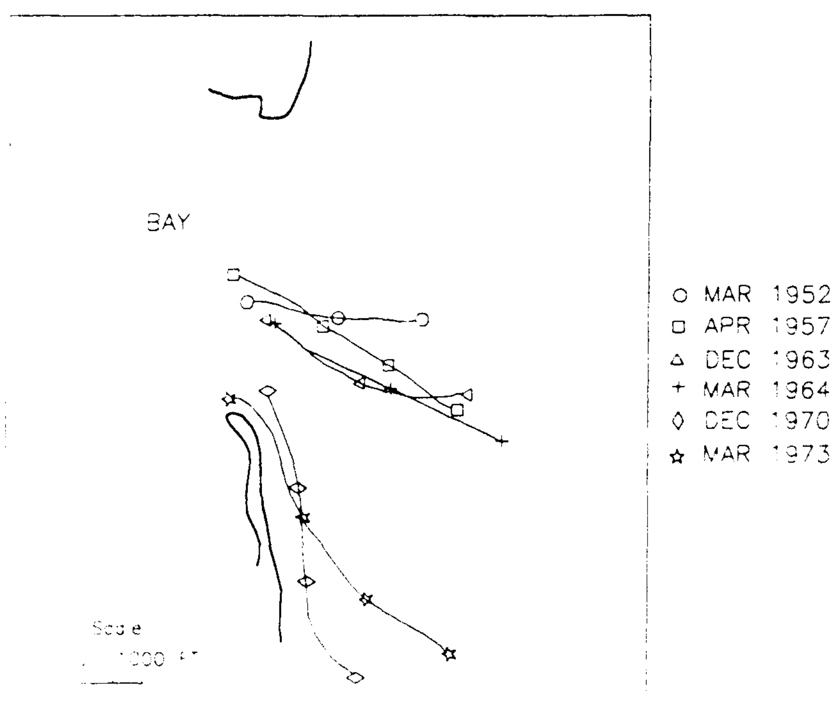

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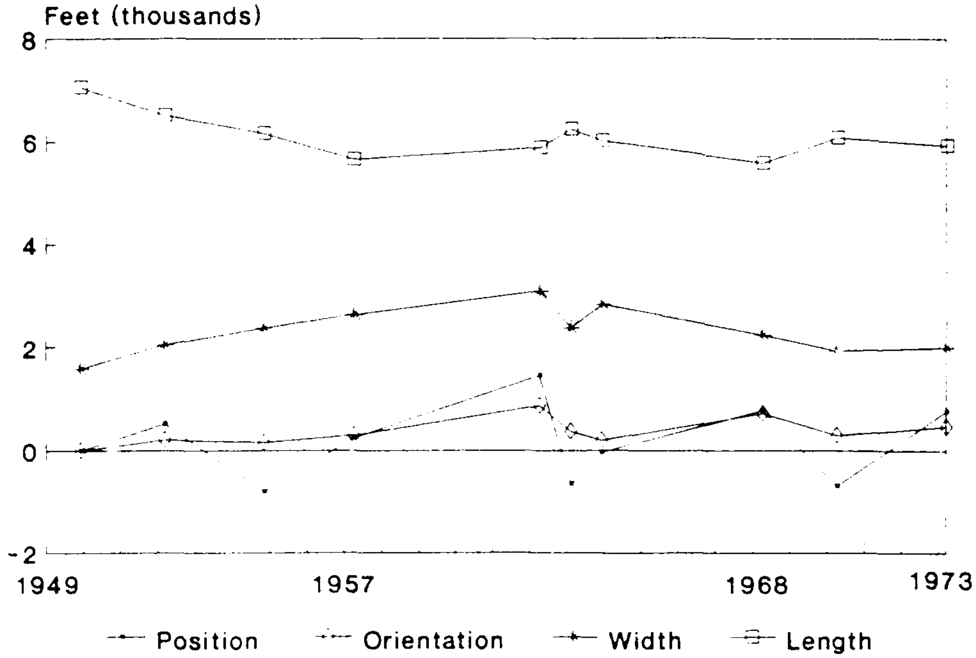
Figure C21. Murrells



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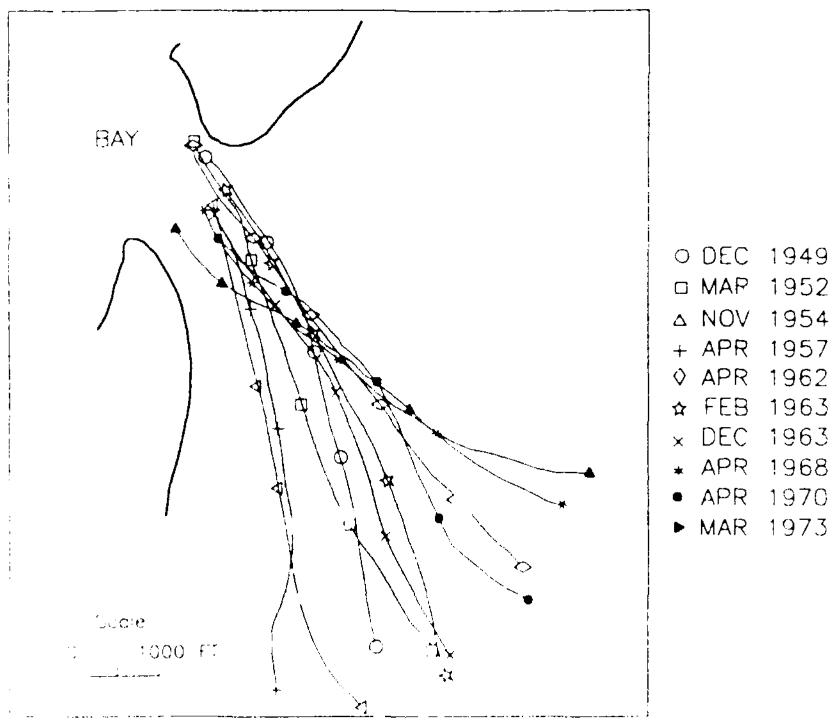

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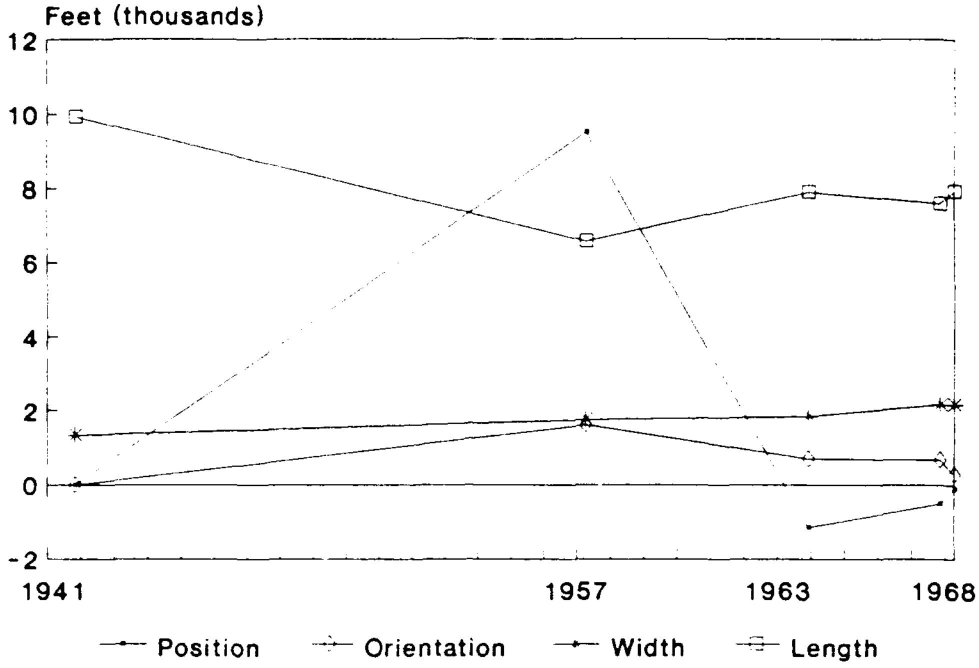
Figure C22. North



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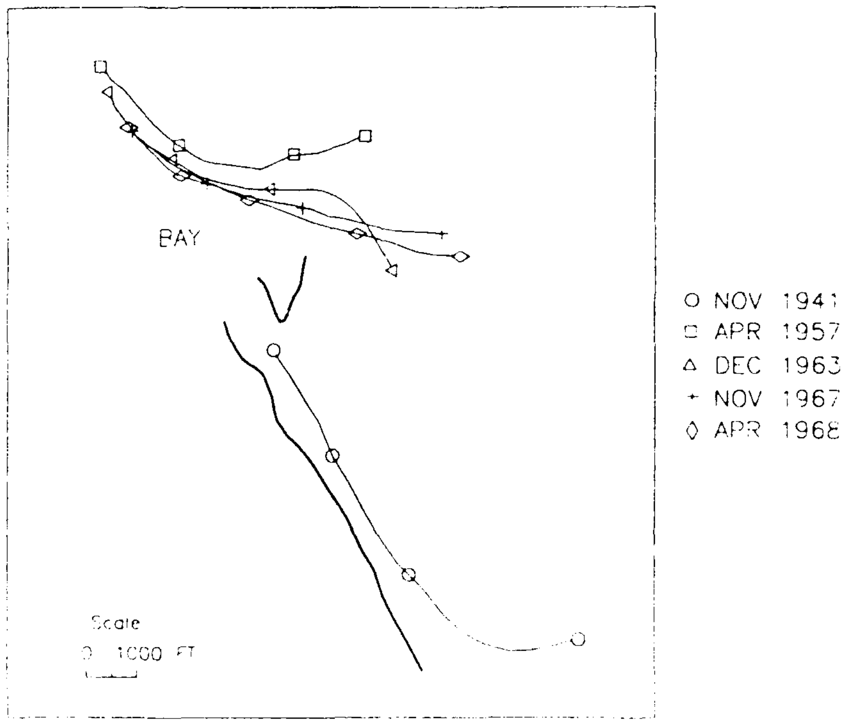

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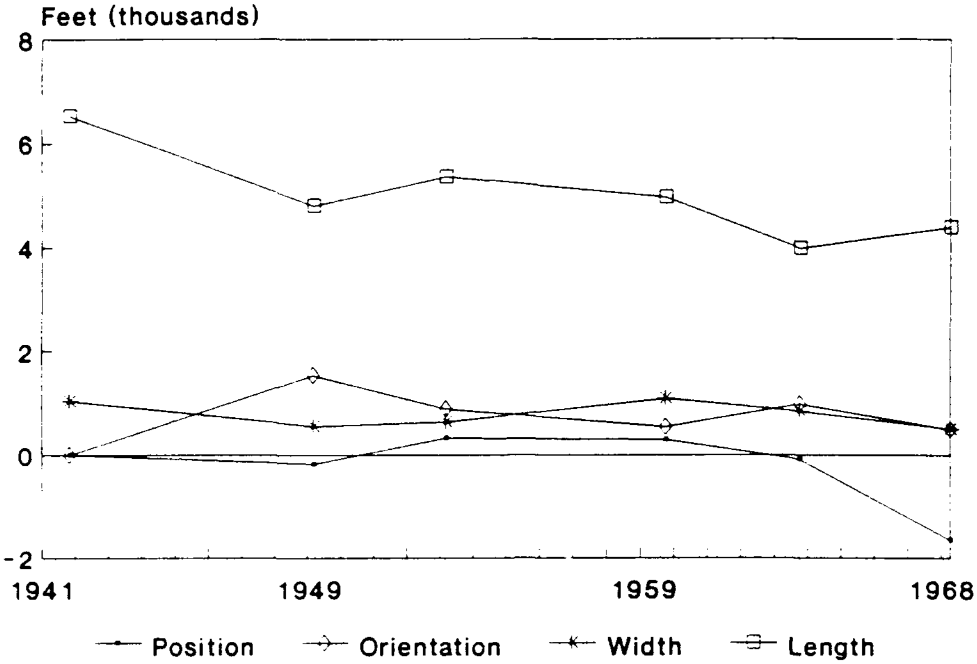
Figure C23. South Santee



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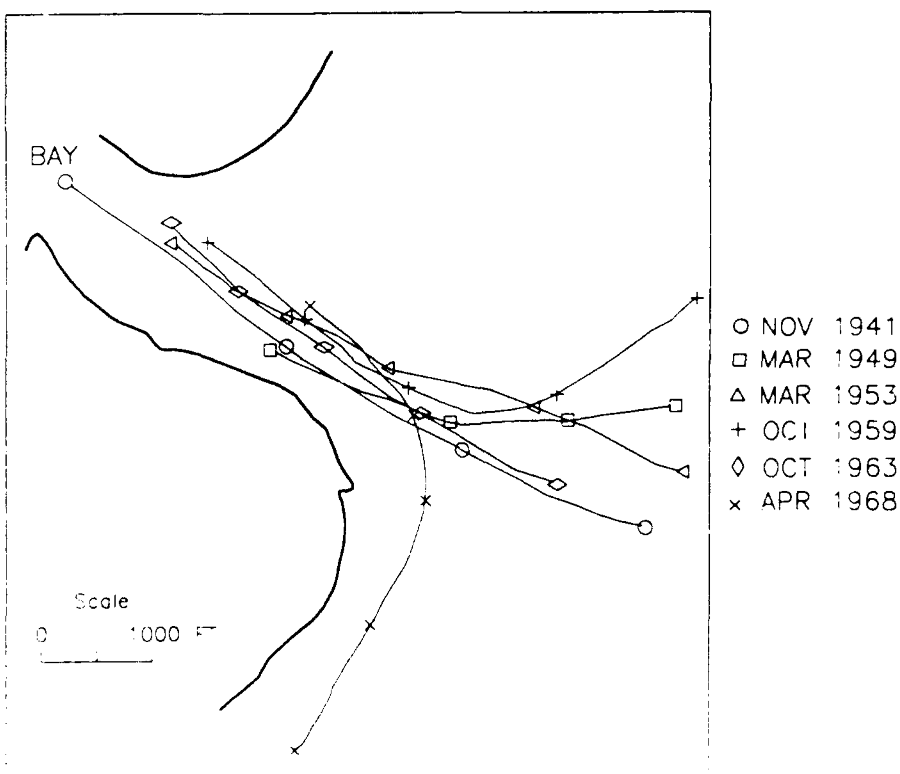

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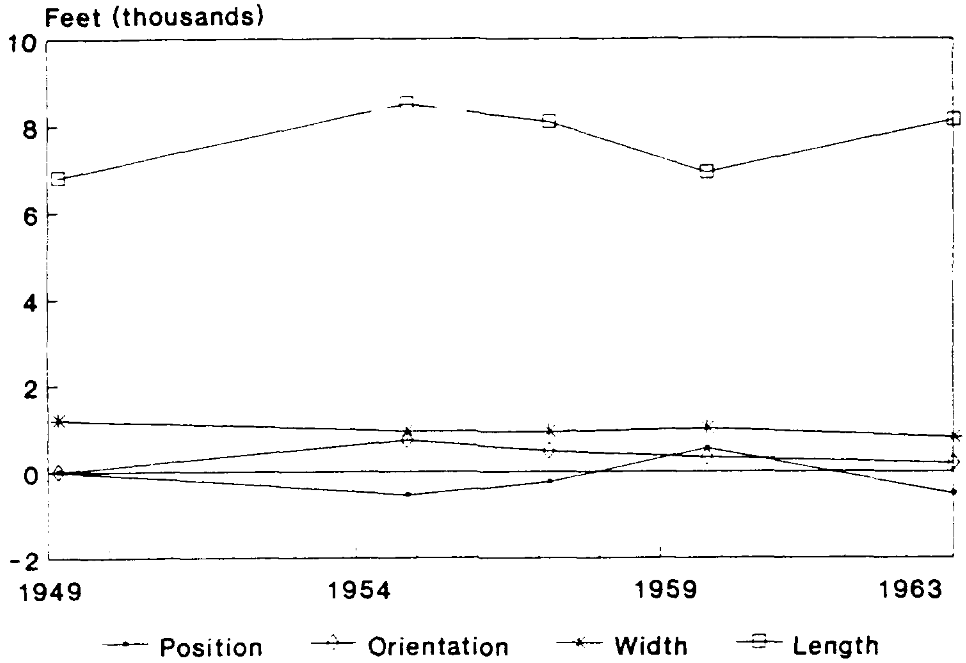
Figure C24. Price



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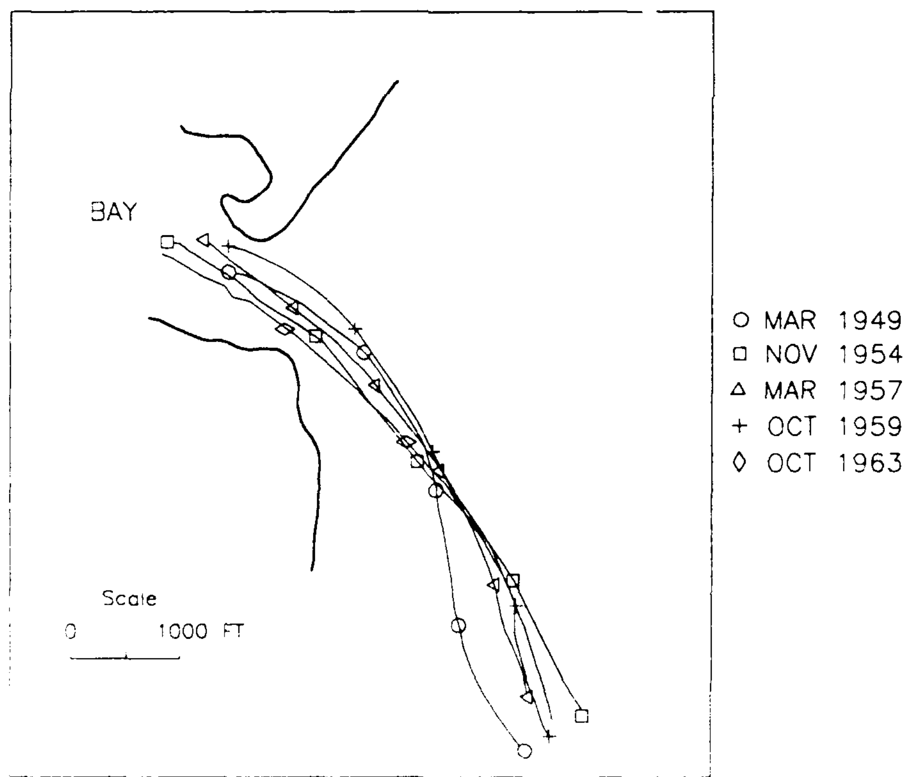

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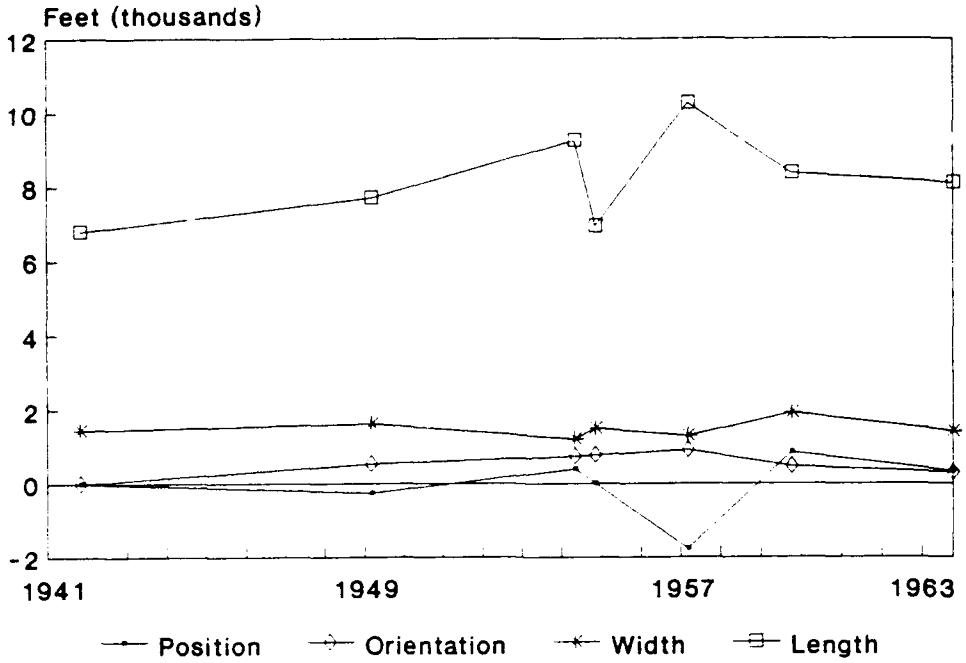
Figure C25. Capers



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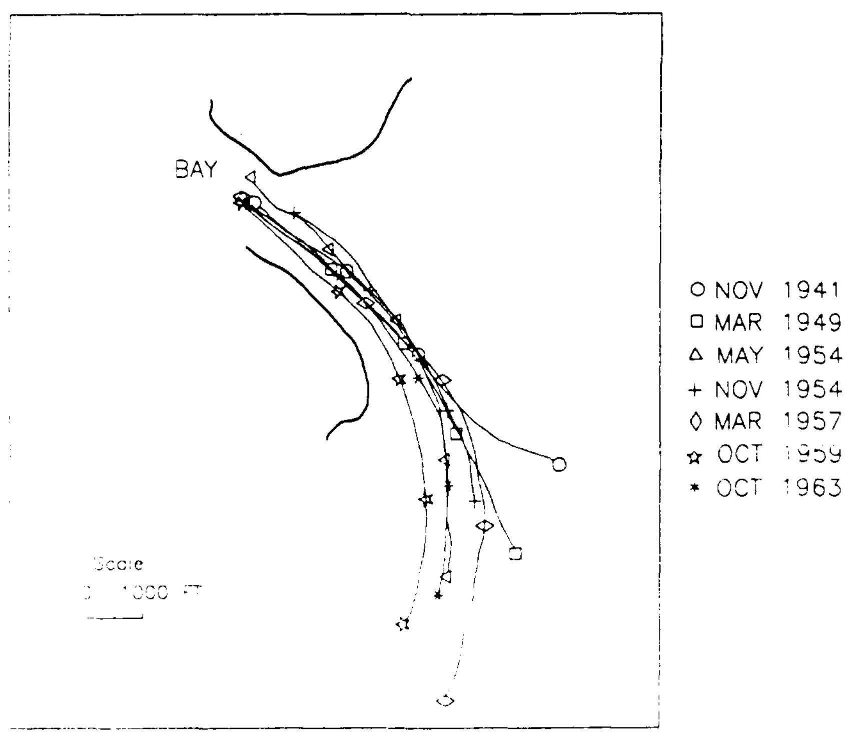

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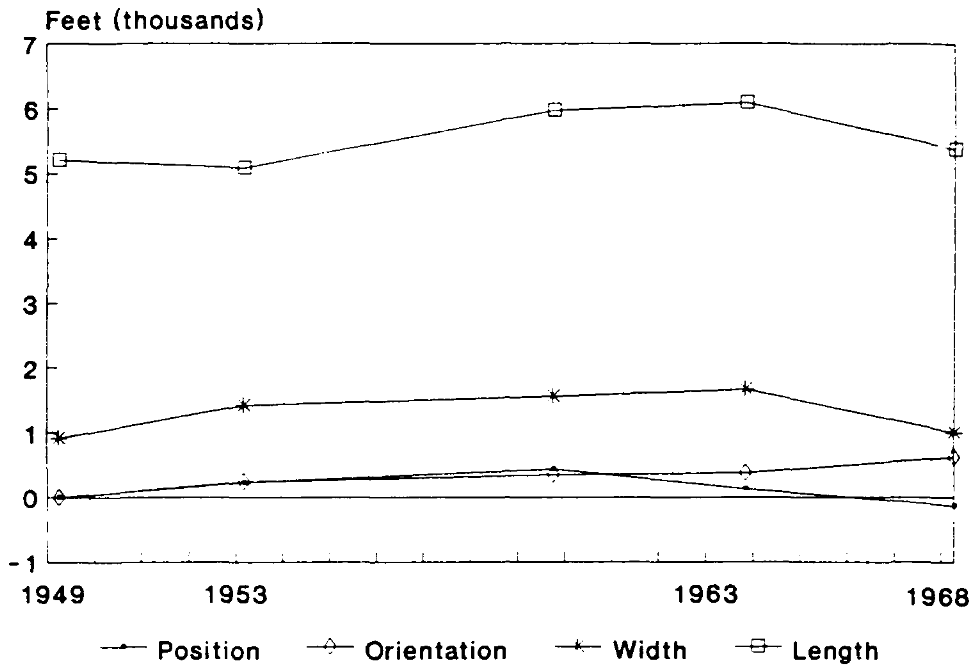
Figure C26. Dewees



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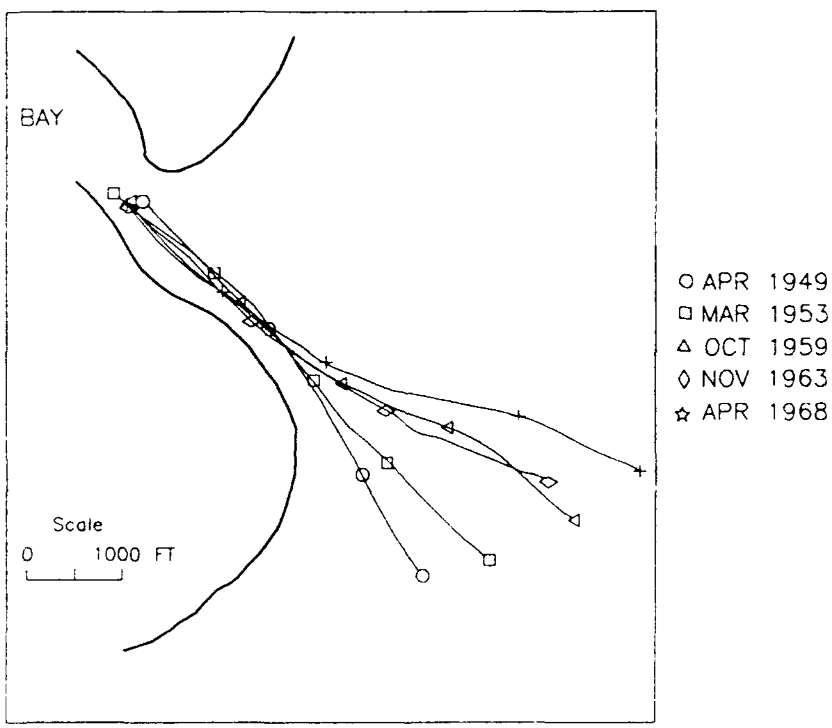

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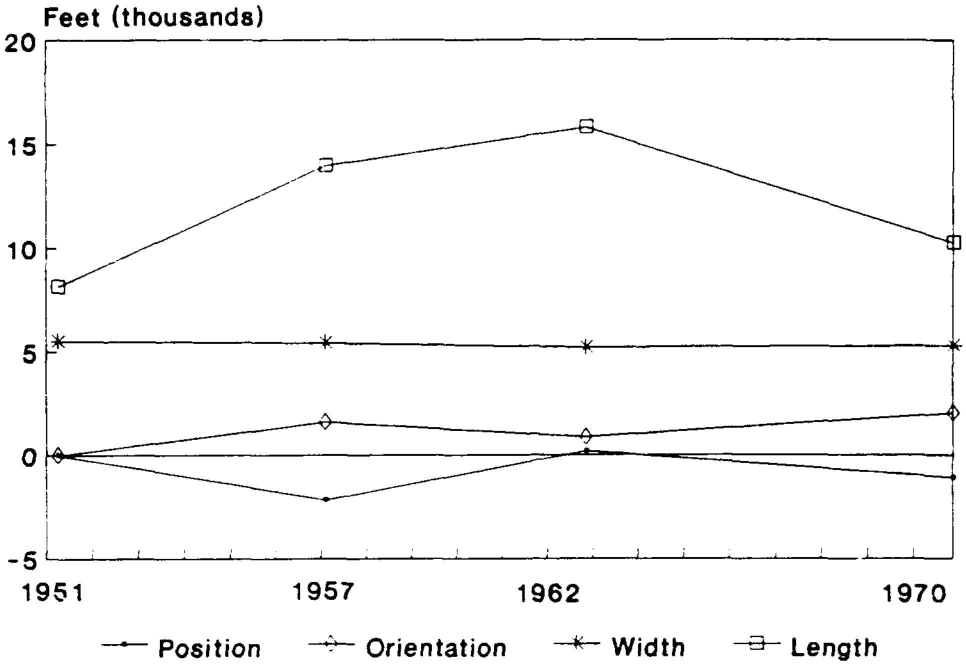
Figure C27. Lighthouse



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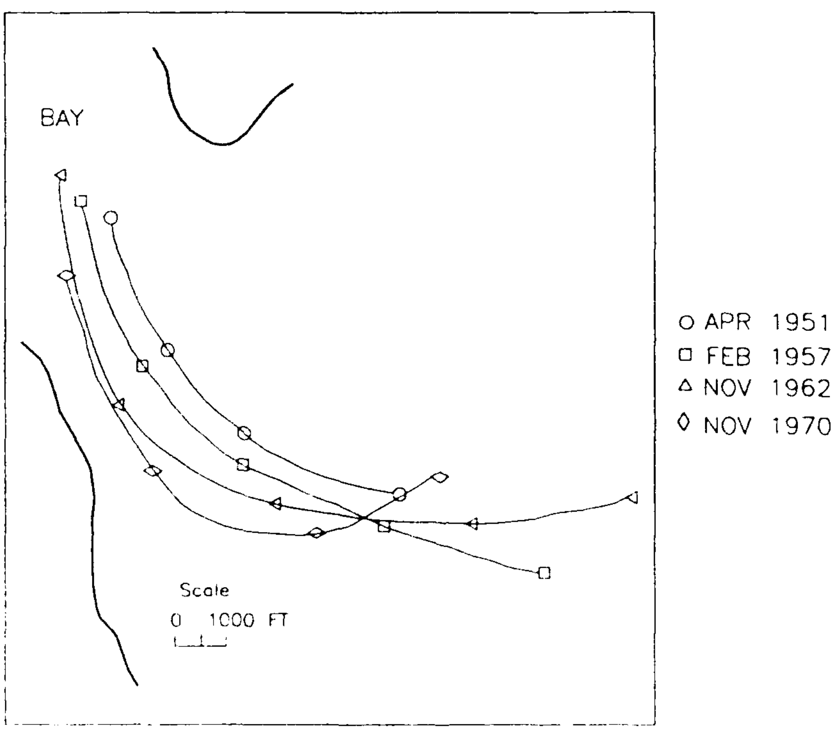

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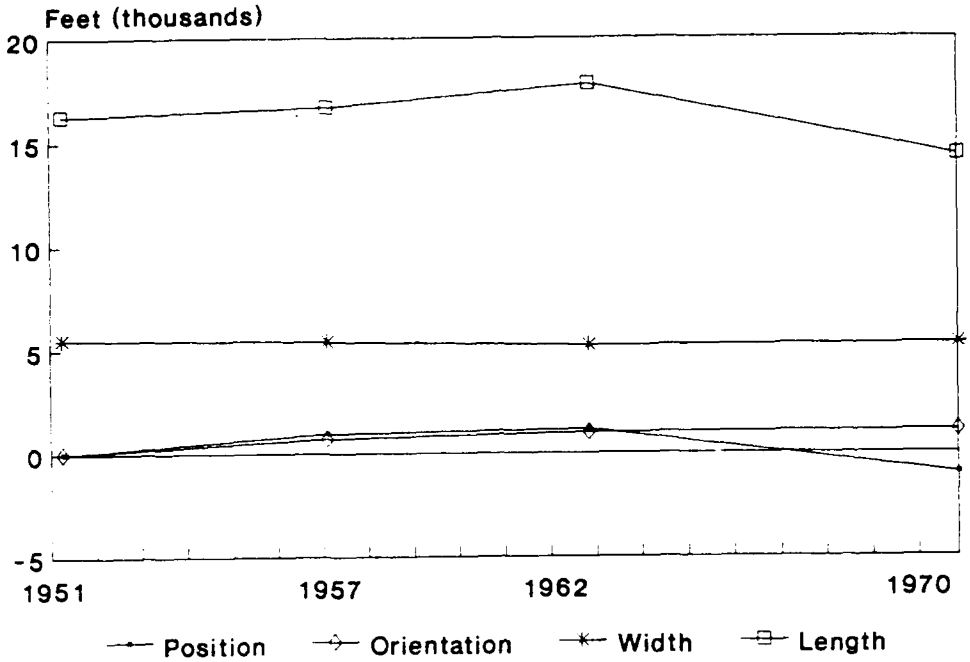
Figure C28. Nassau-N



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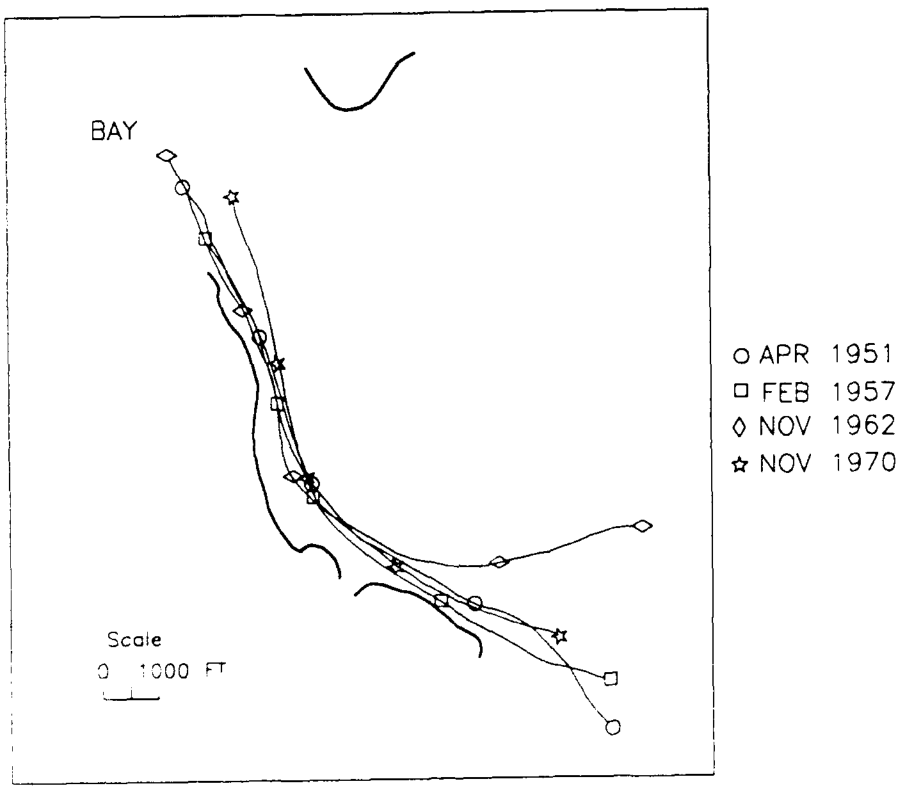

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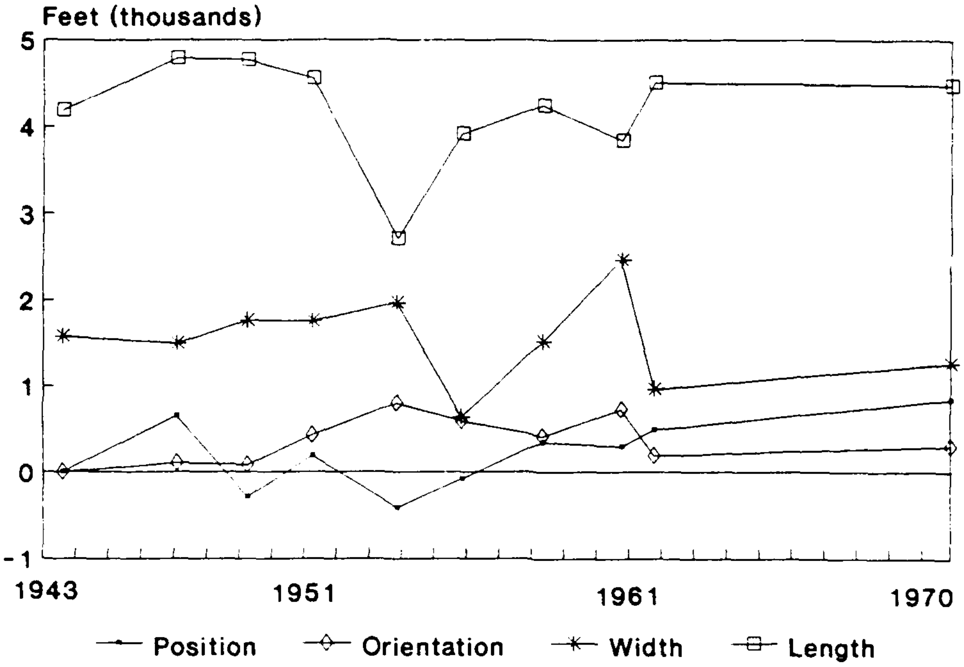
Figure C29. Nassau-S



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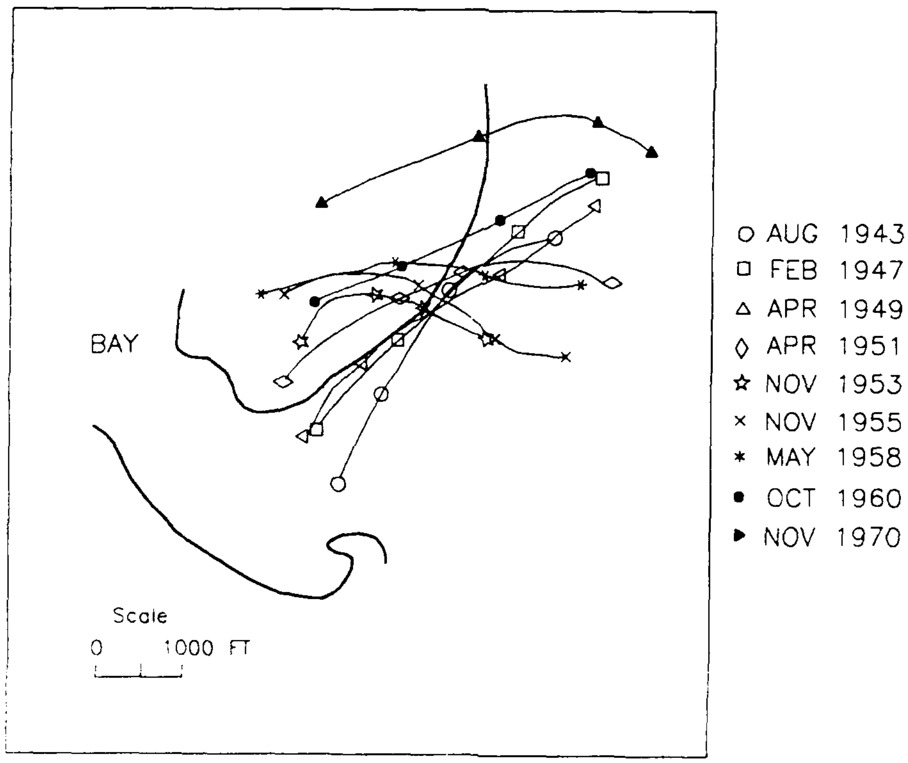

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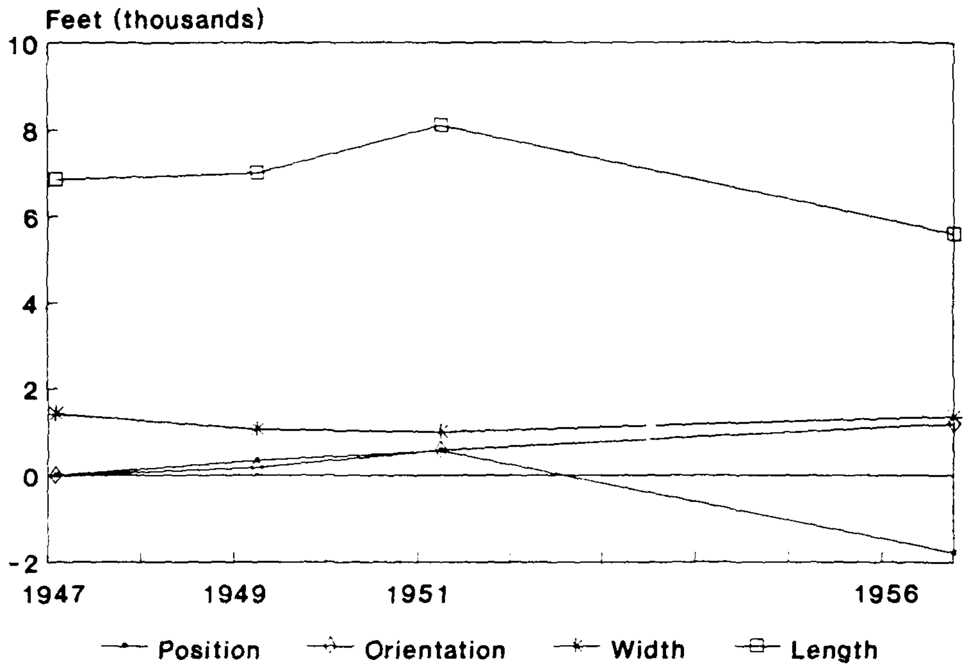
Figure C30. Ft. George



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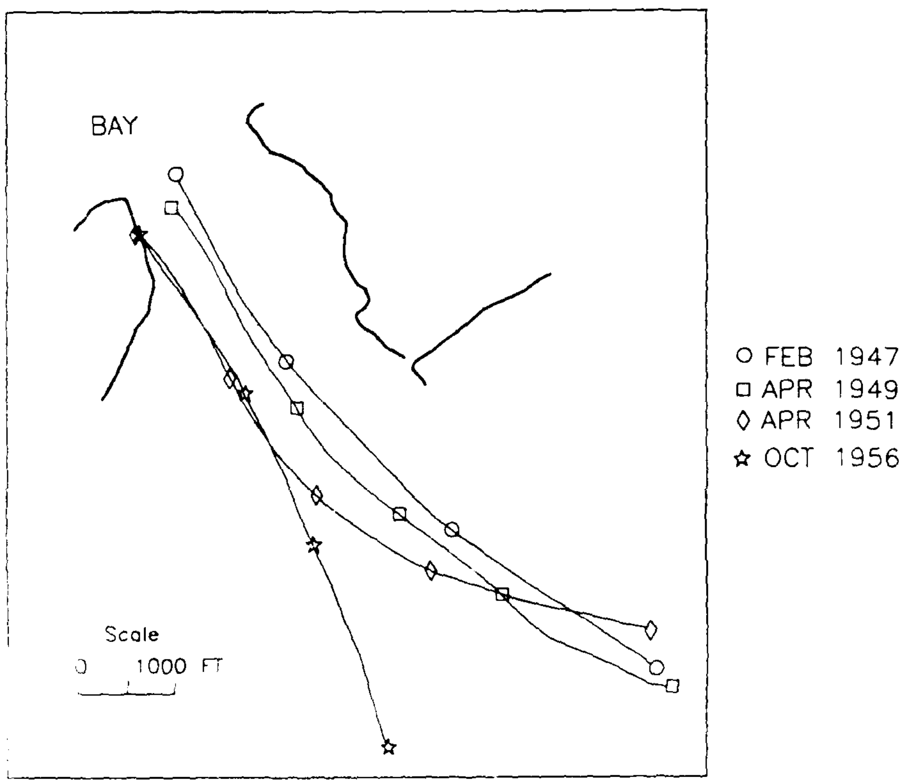

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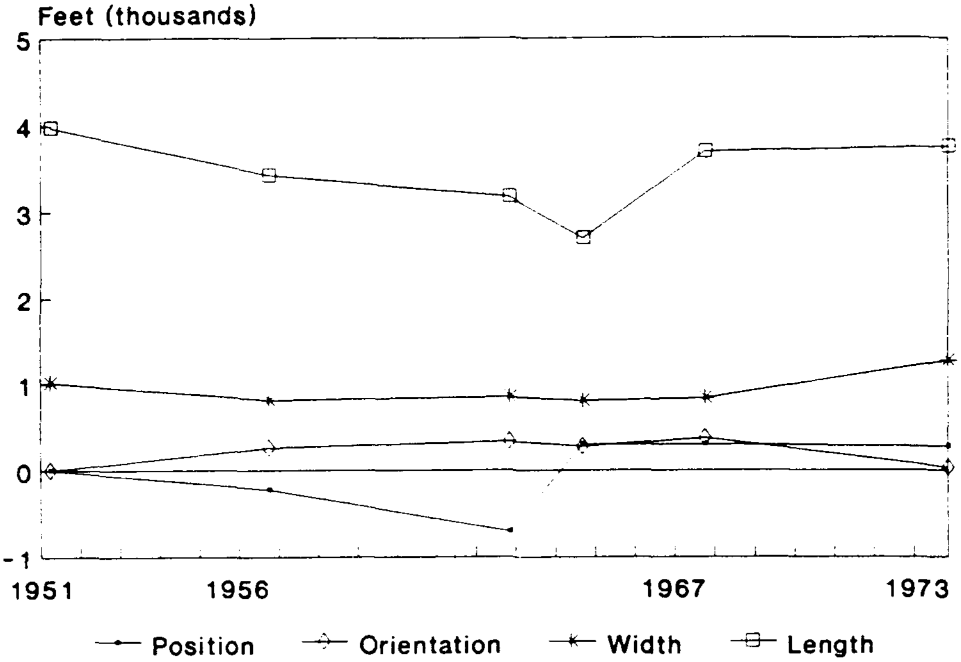
Figure C31. St. Augustine



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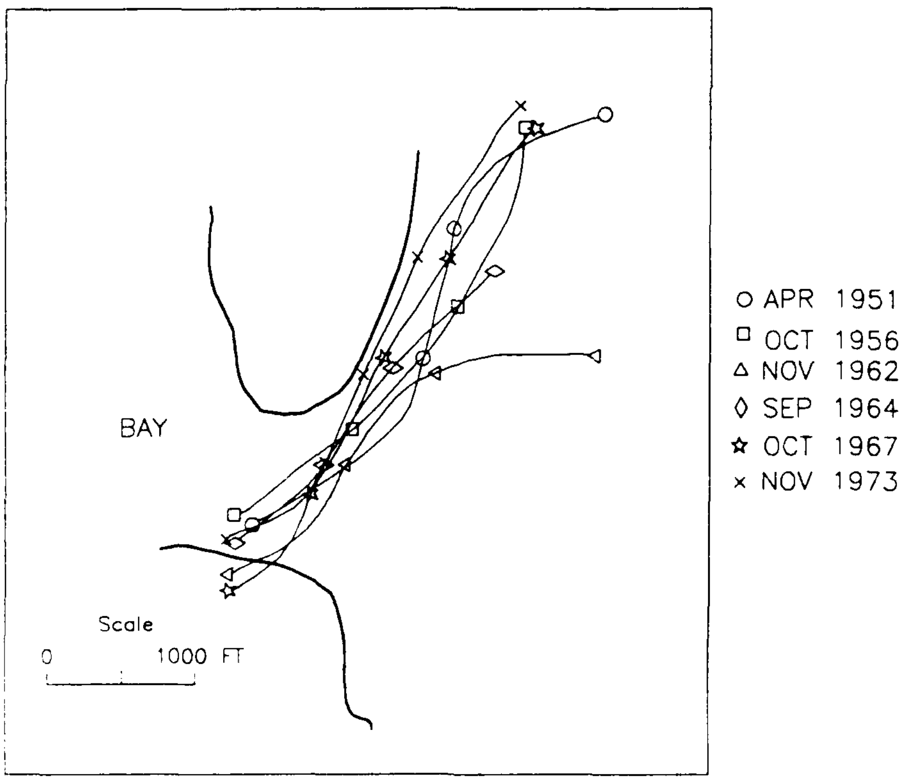

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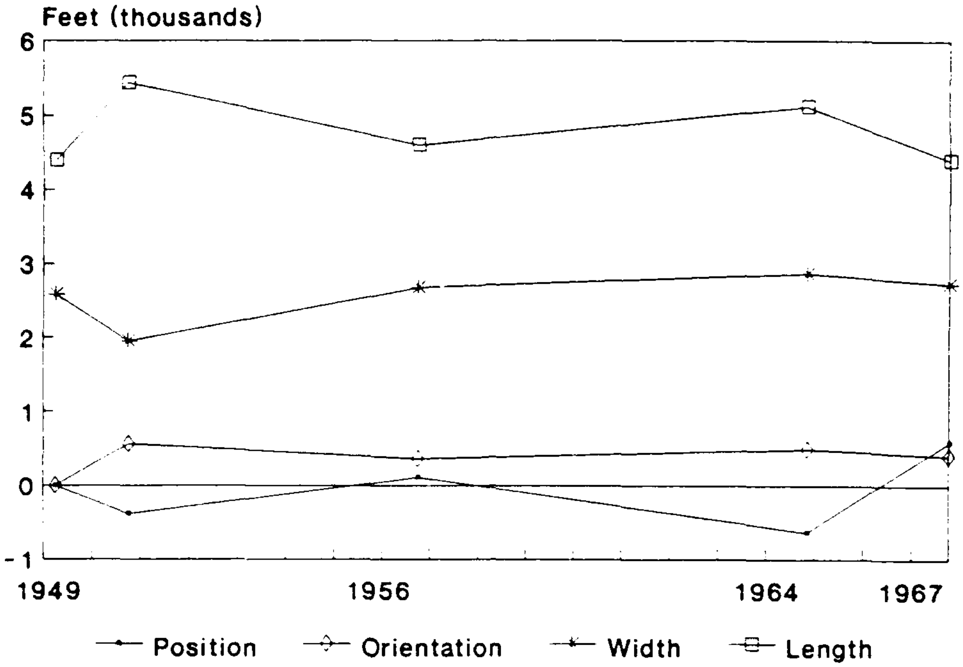
Figure C32. Mantanzas



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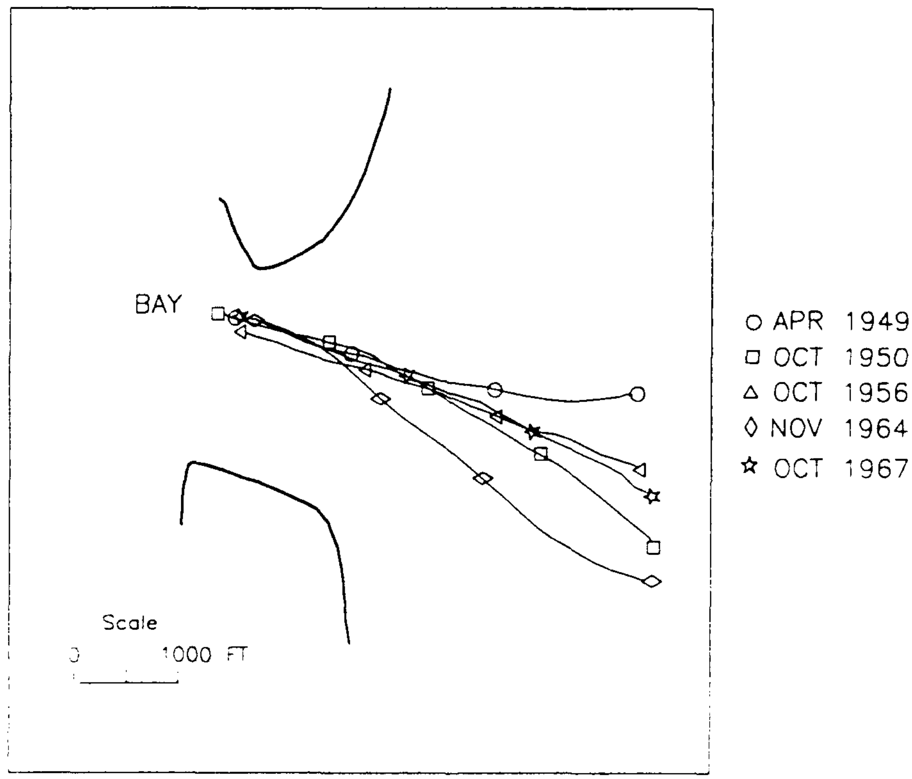

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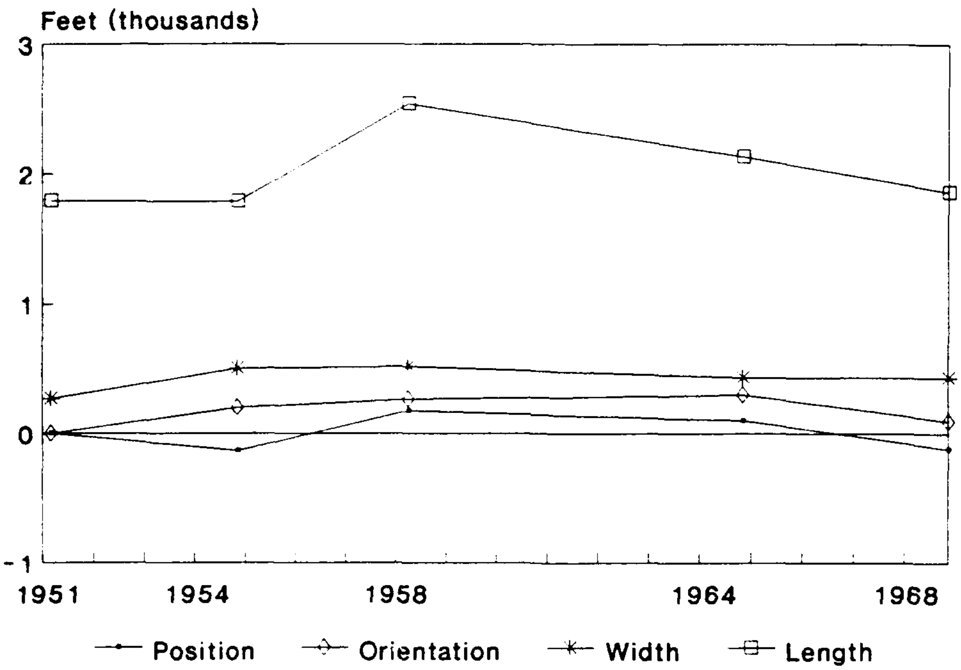
Figure C33. Ponce De Leon



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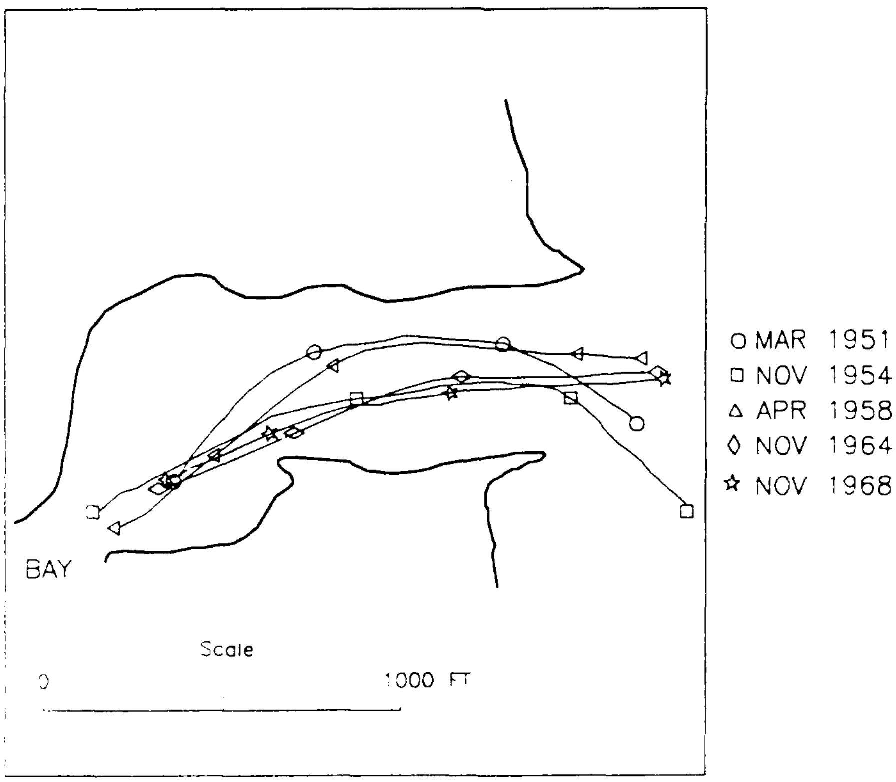

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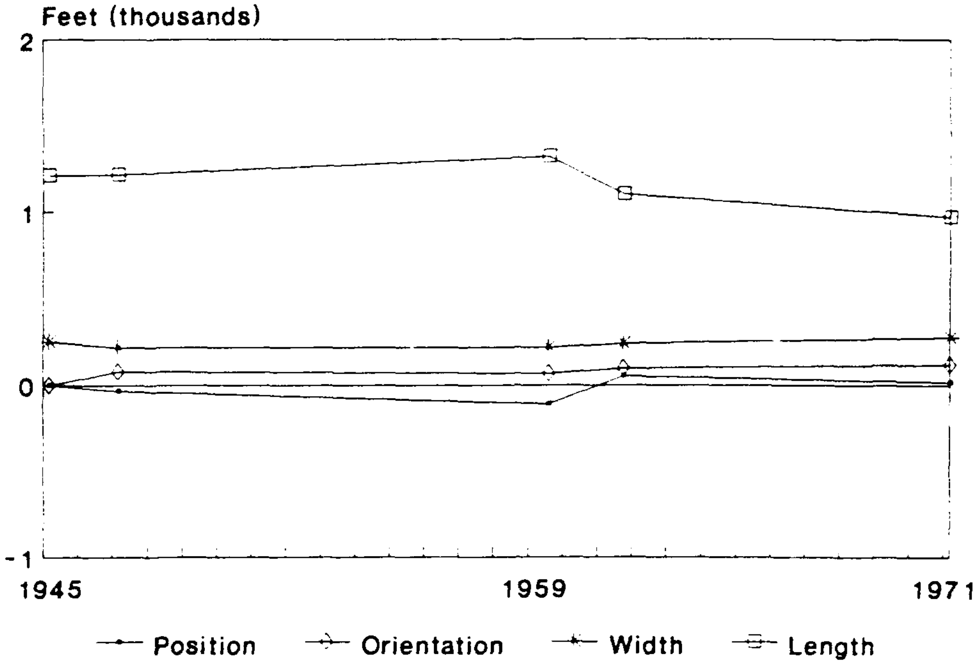
Figure C34. Sebastian



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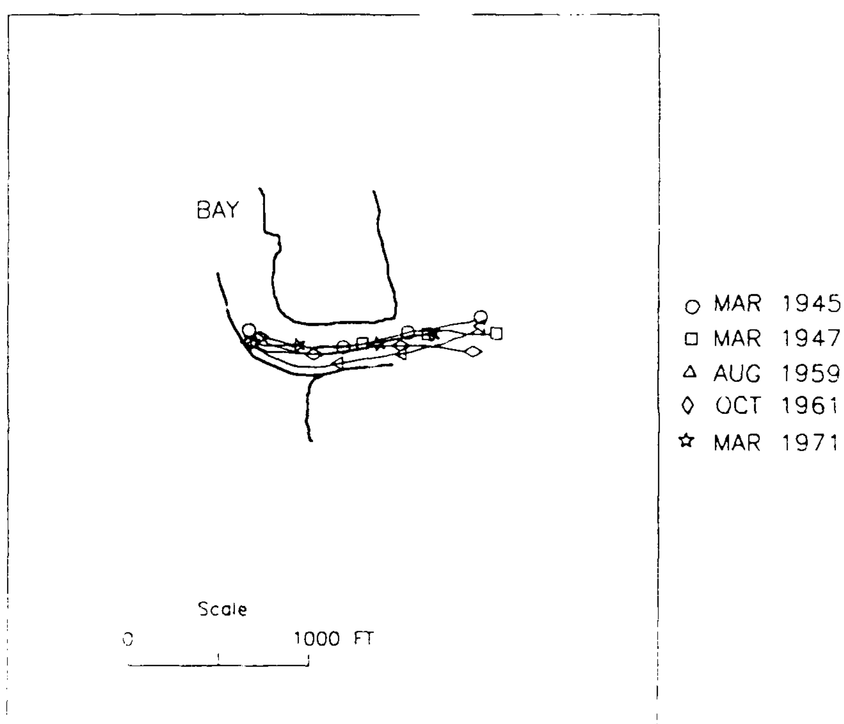

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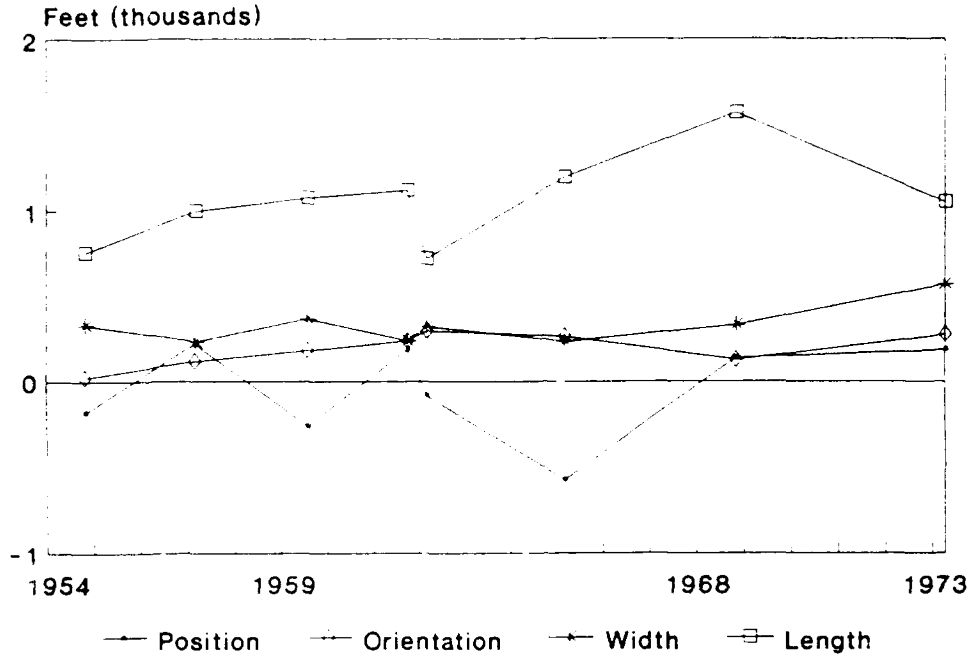
Figure C35. Boca Raton



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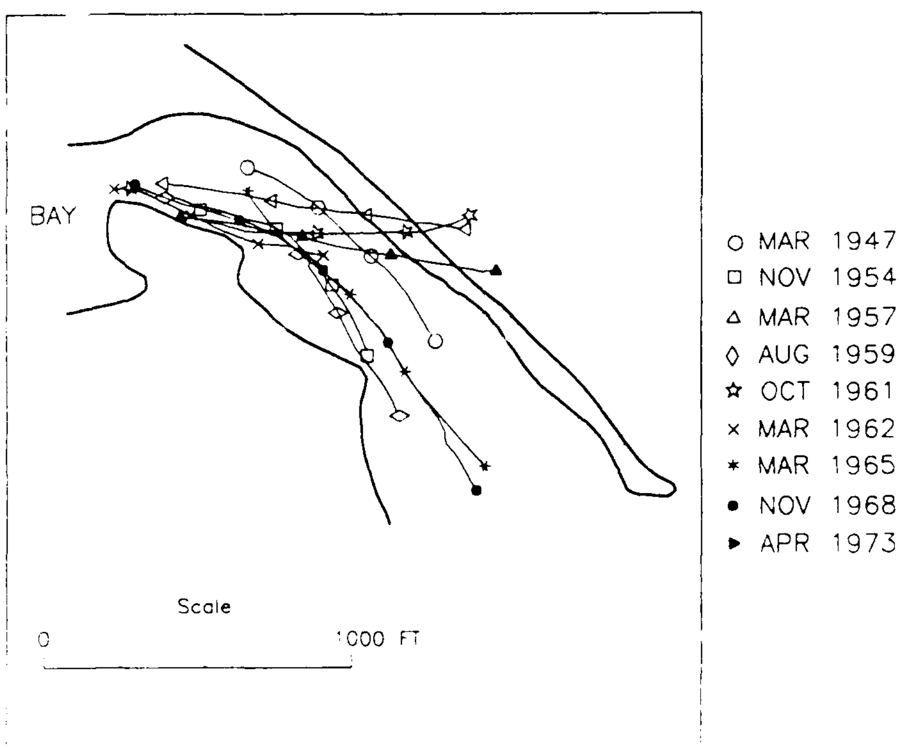

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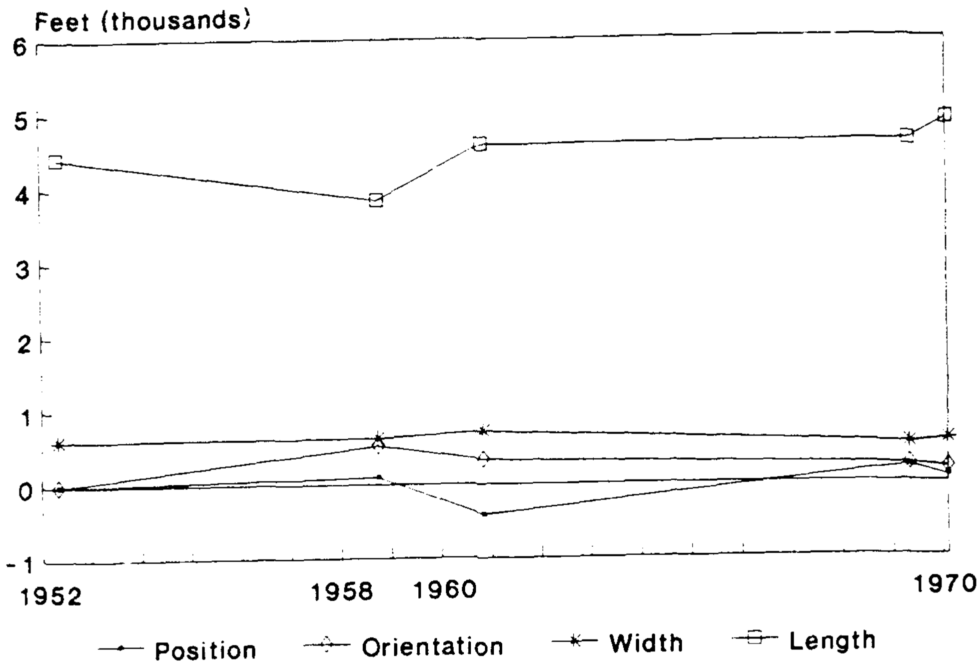
Figure C36. Hillsboro



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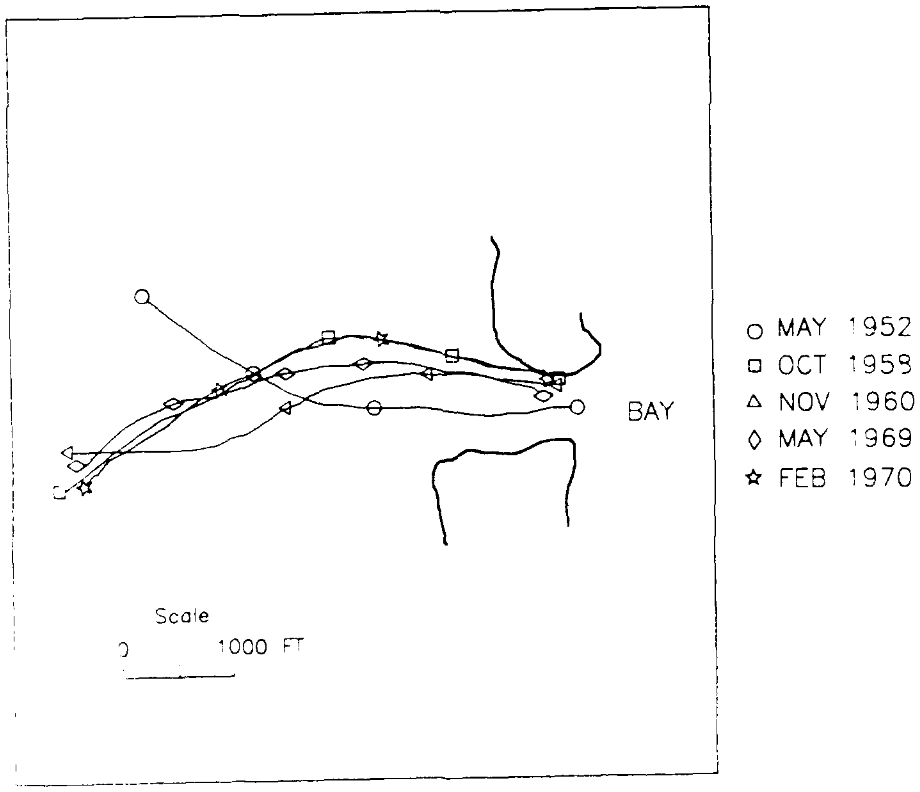

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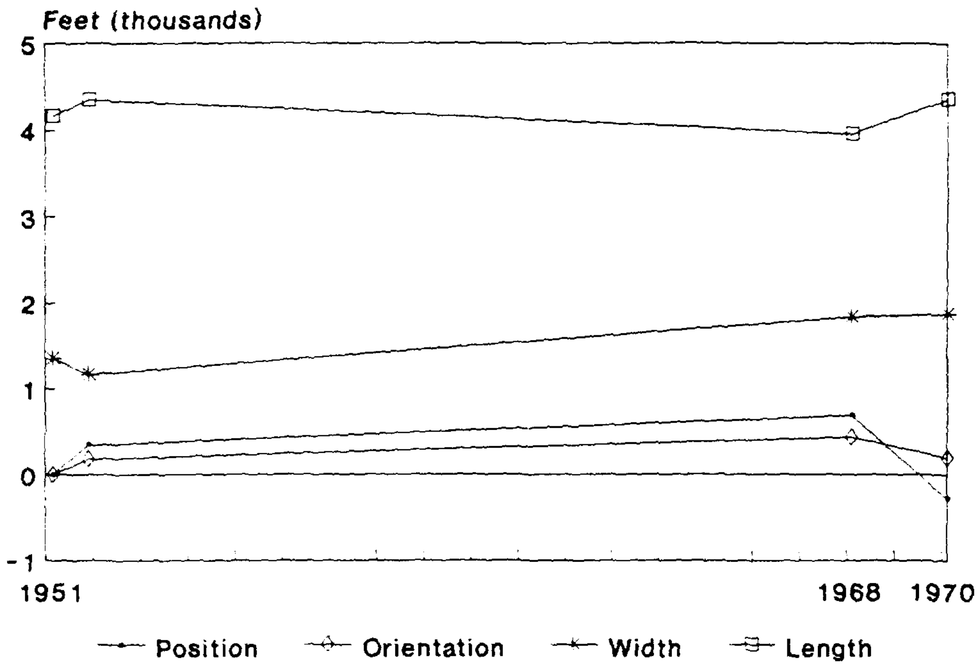
Figure C37. Redfish



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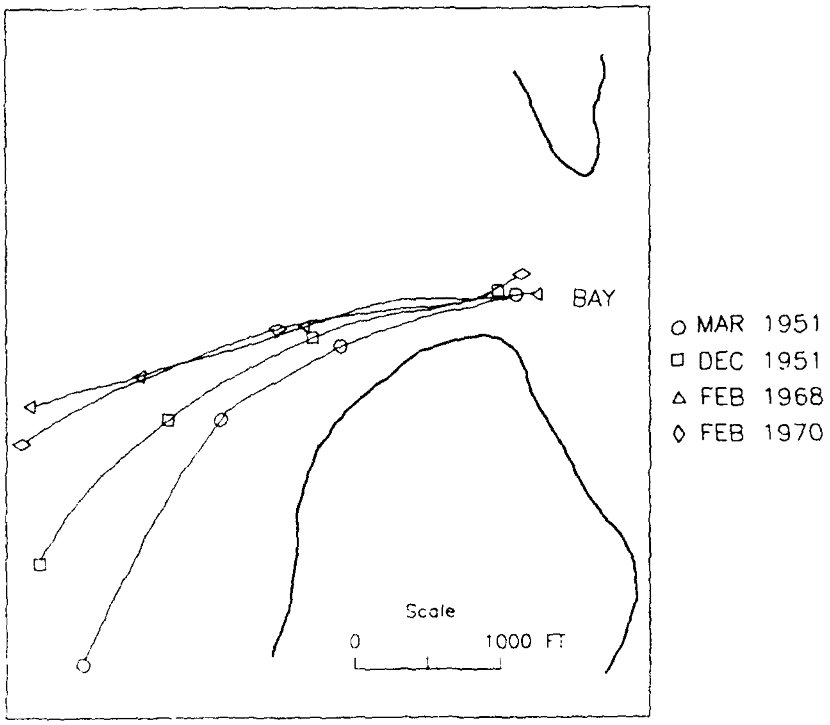

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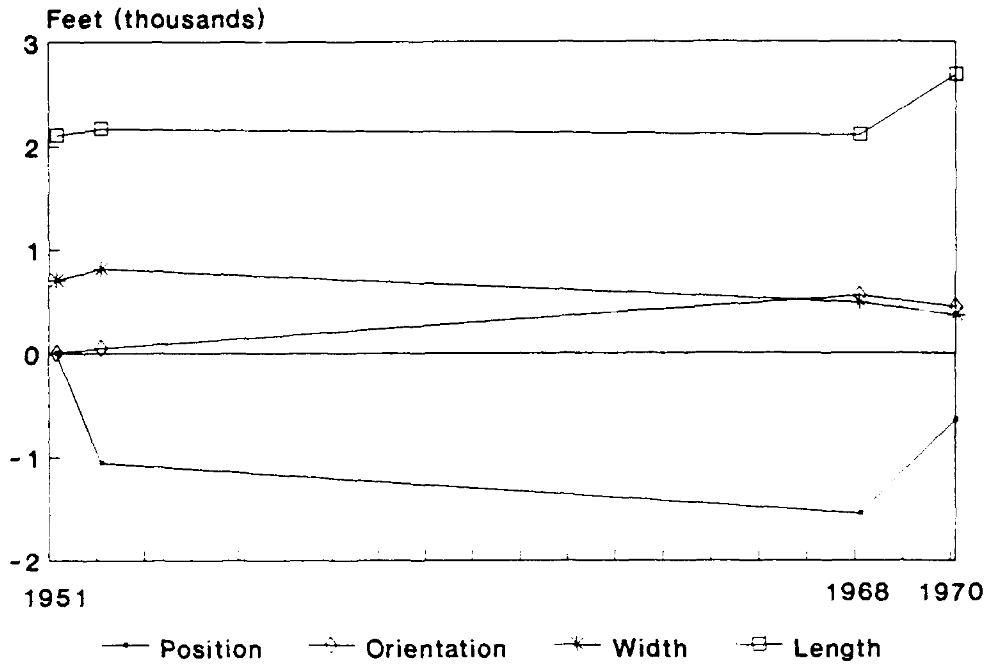
Figure C38. Gasparilla



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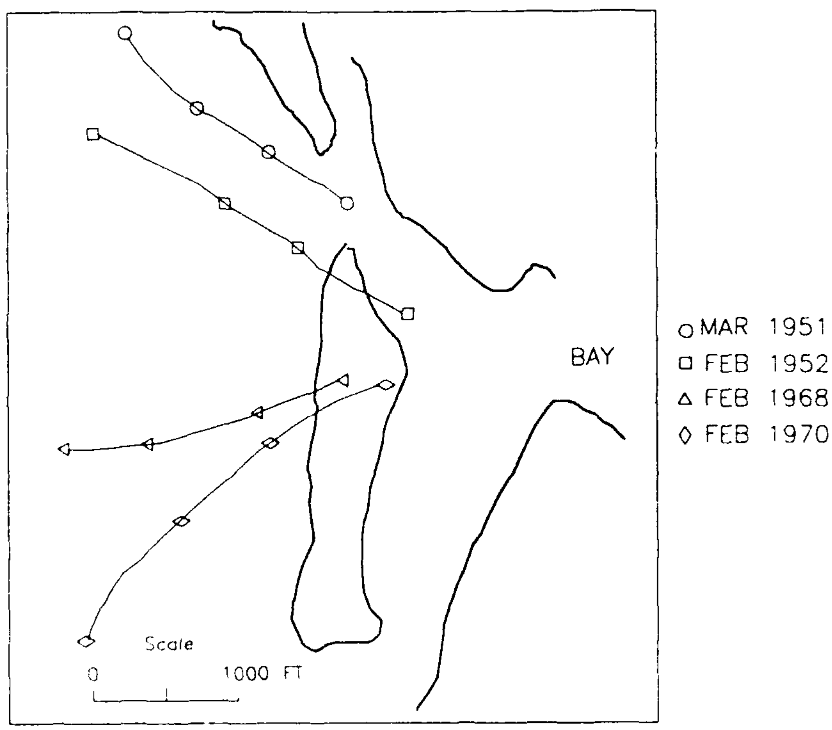

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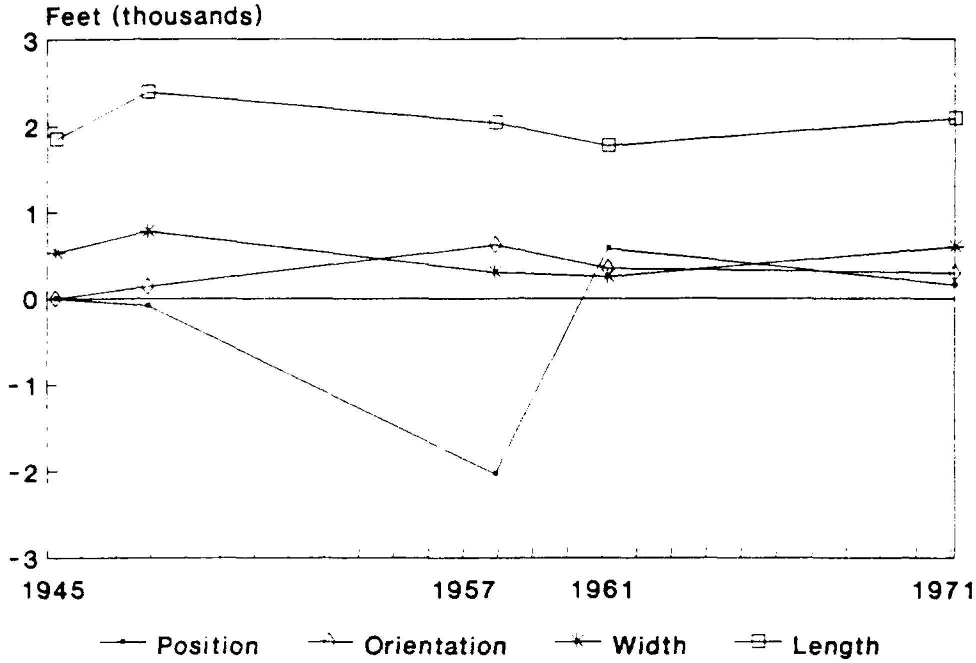
Figure C39. Stump



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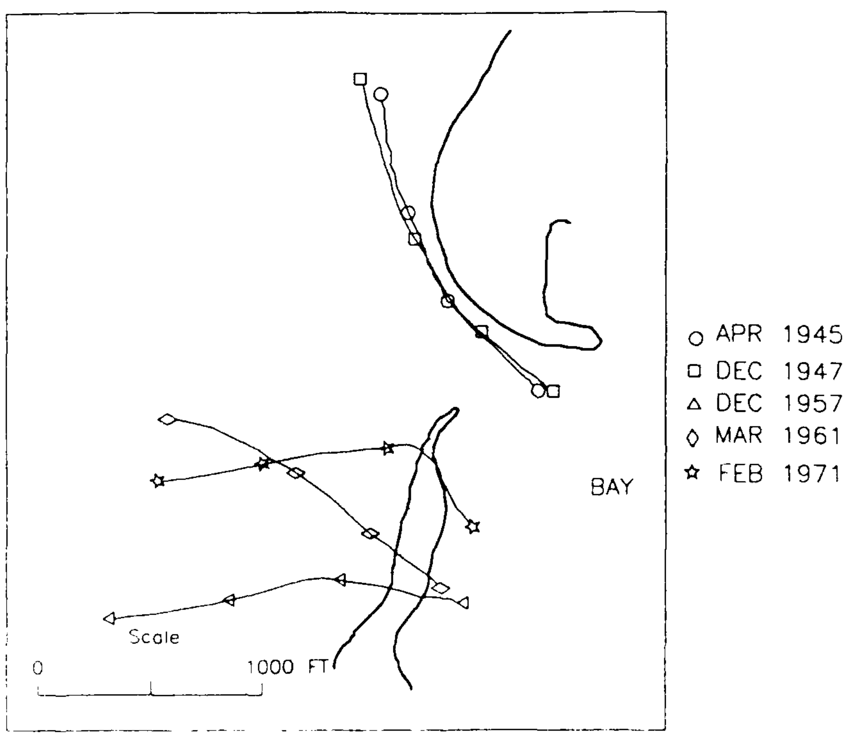

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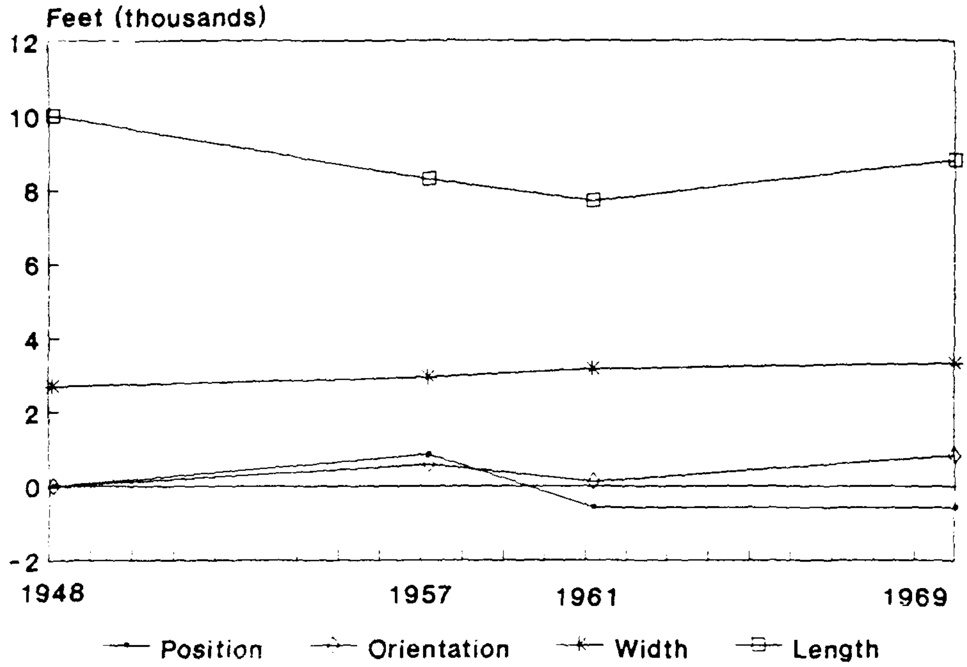
Figure C40. Midnight



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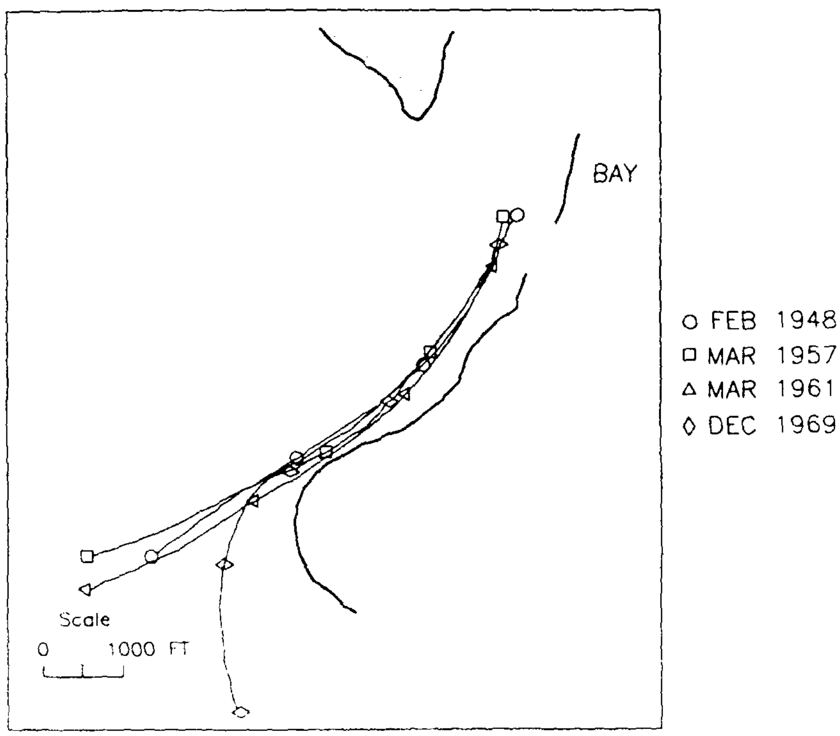

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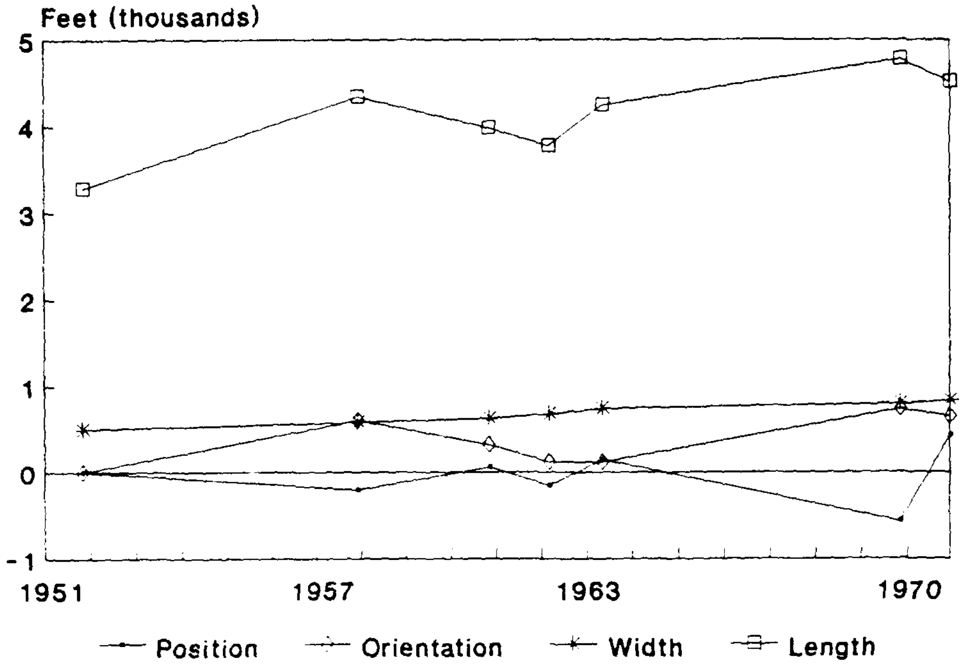
Figure C41. Big Sarasota



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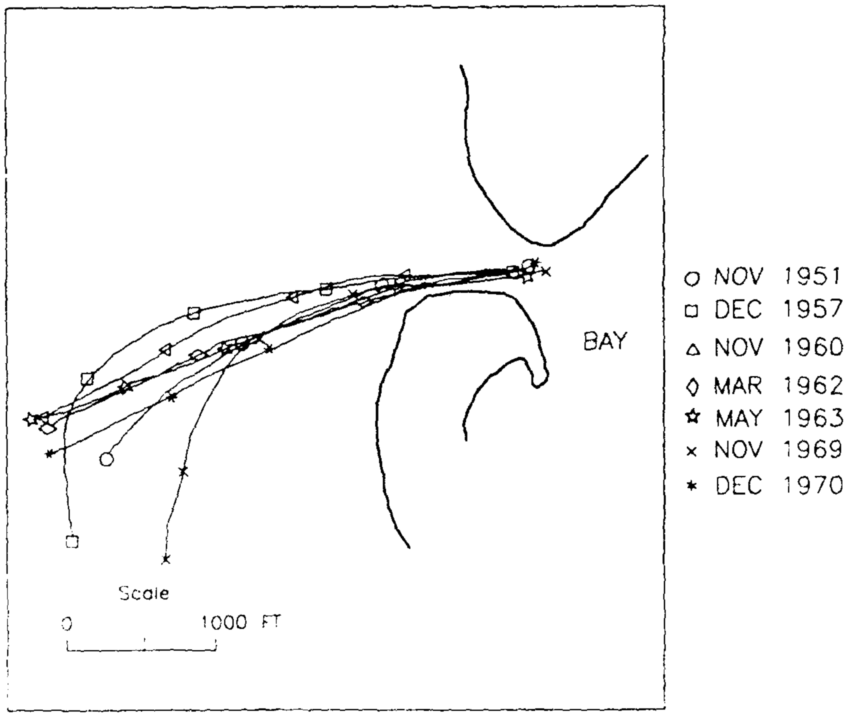

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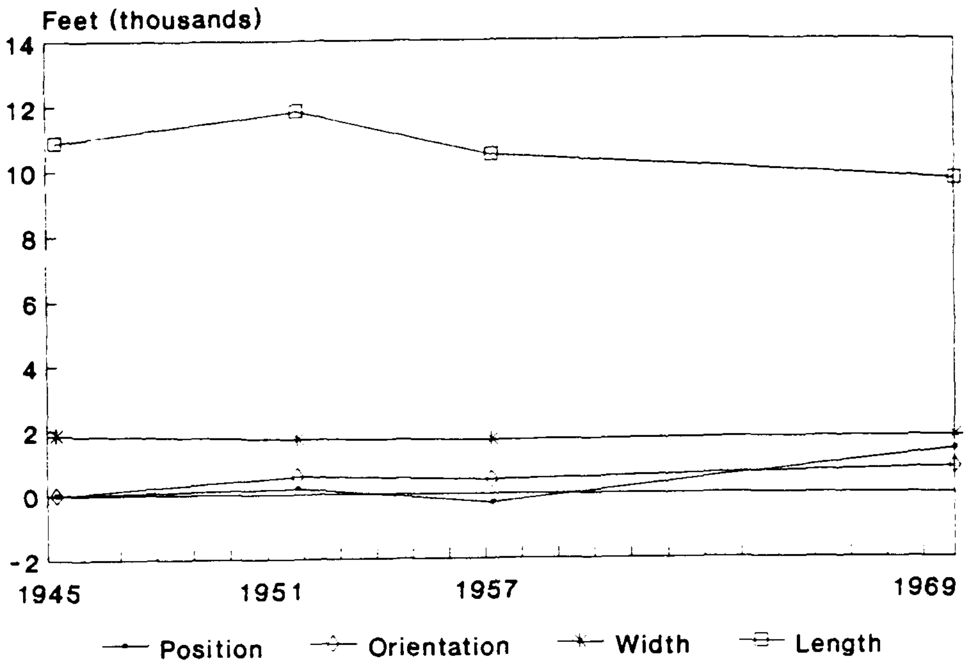
Figure C42. Longboat



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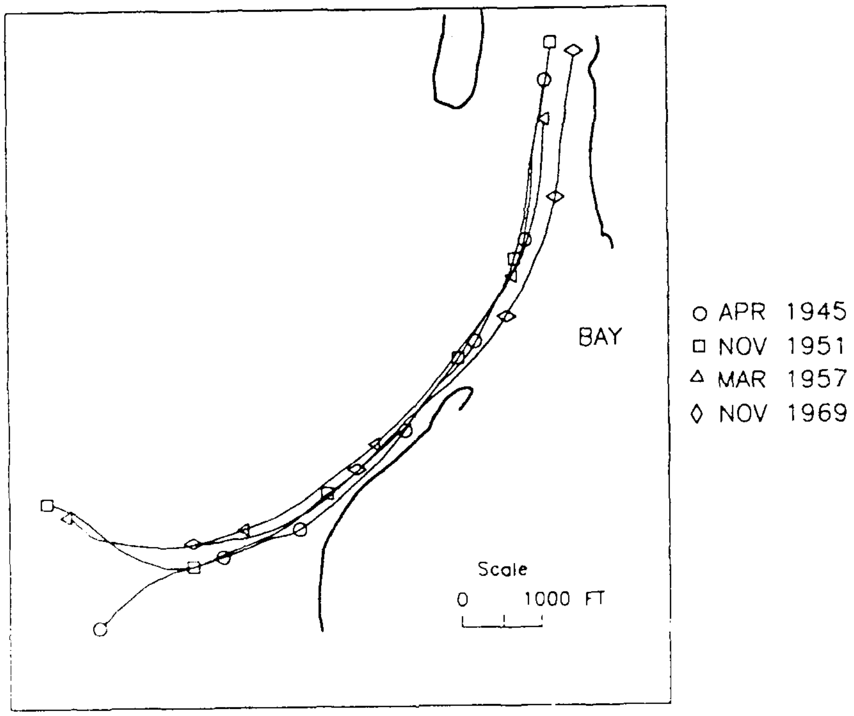

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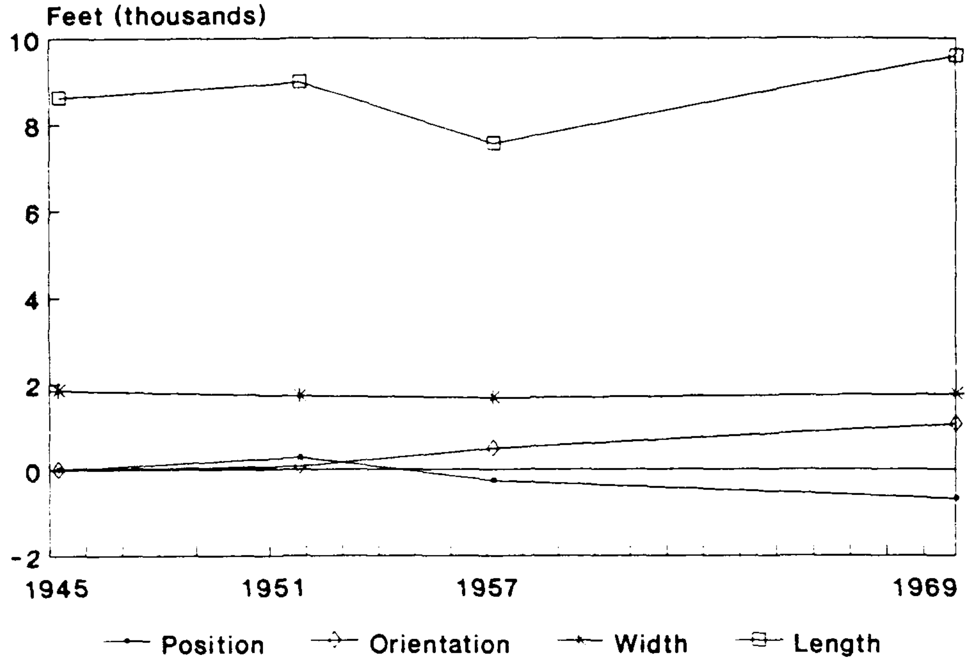
Figure C43. Pass A Grille-S



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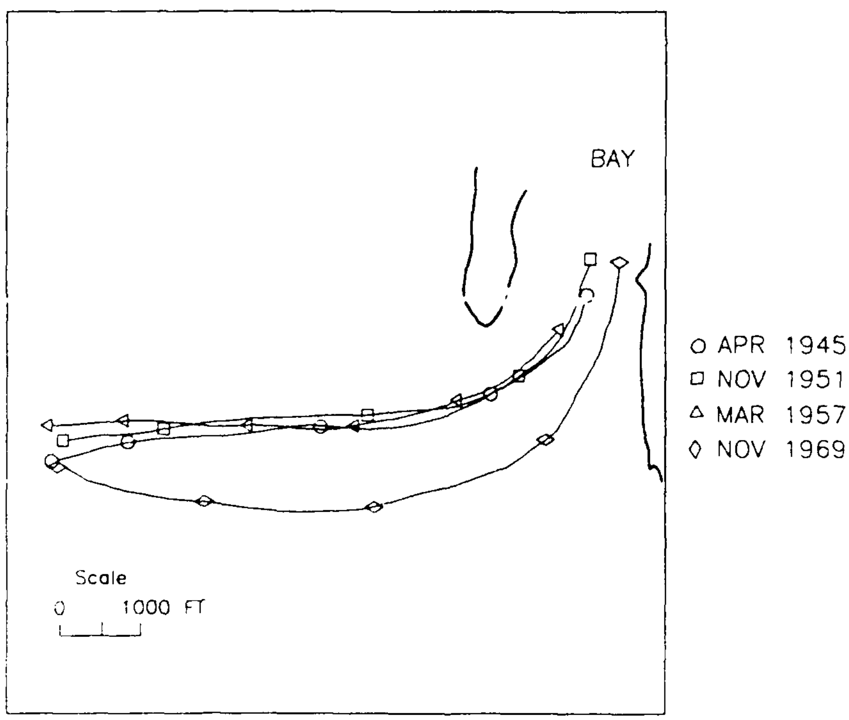

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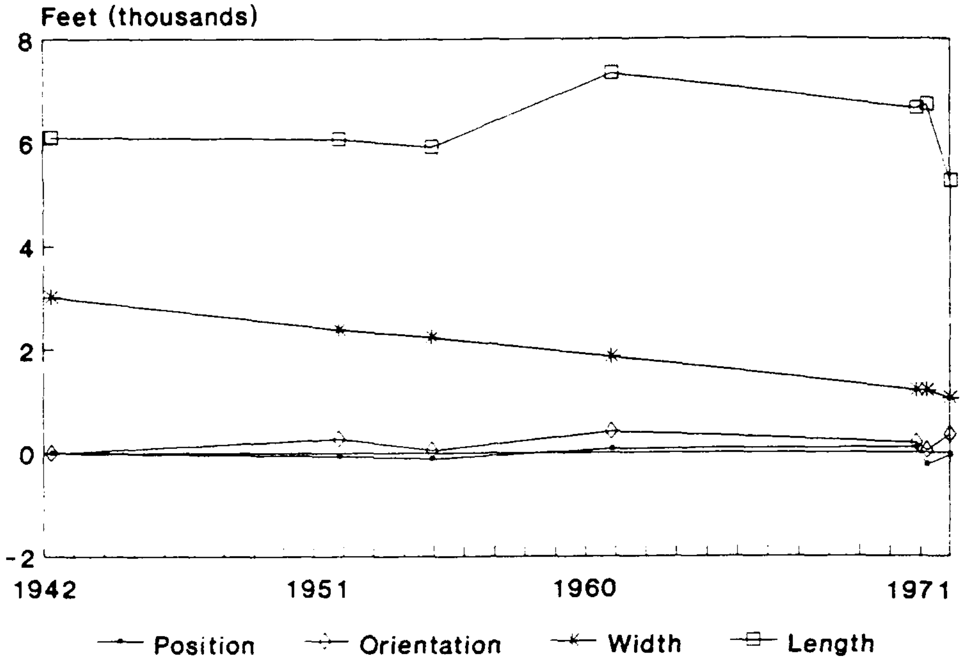
Figure C44. Pass A Grille-N



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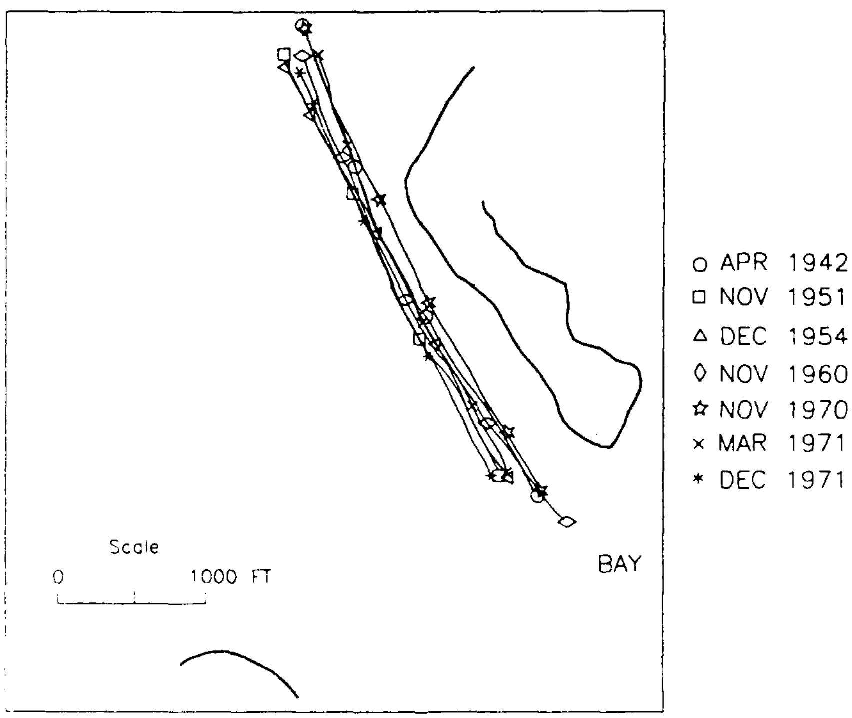

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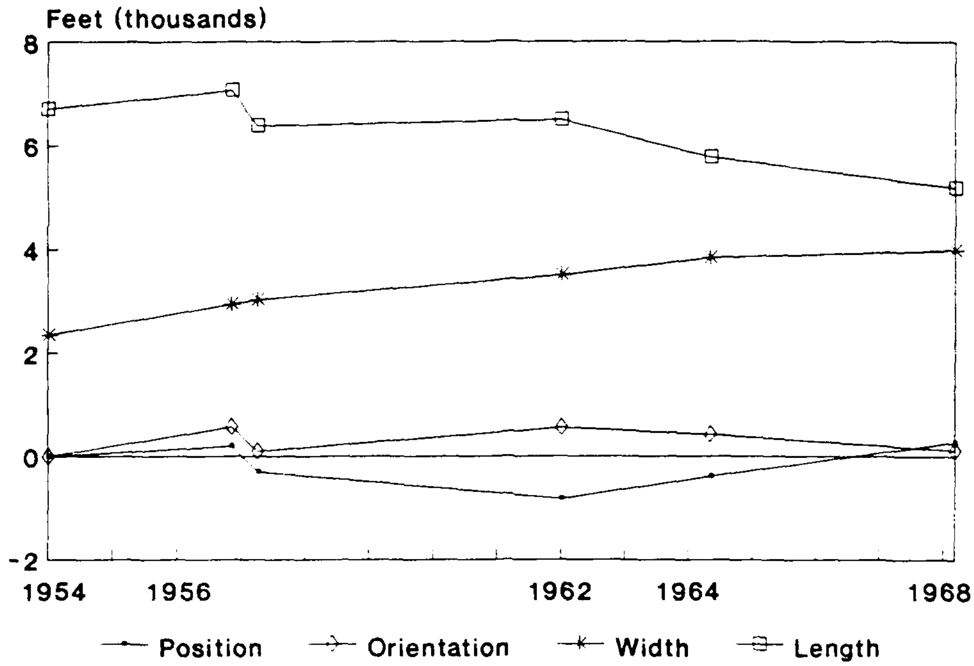
Figure C45. Clearwater



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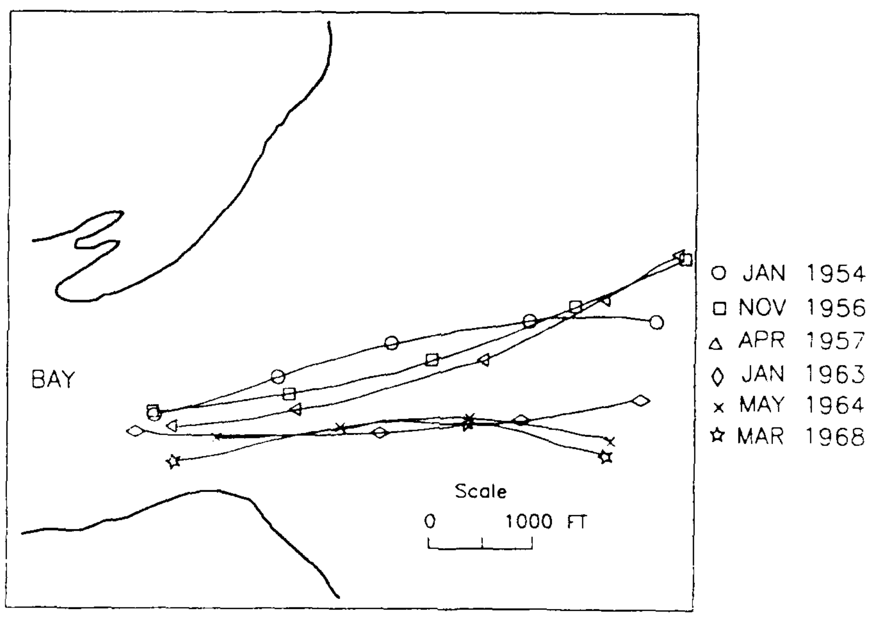

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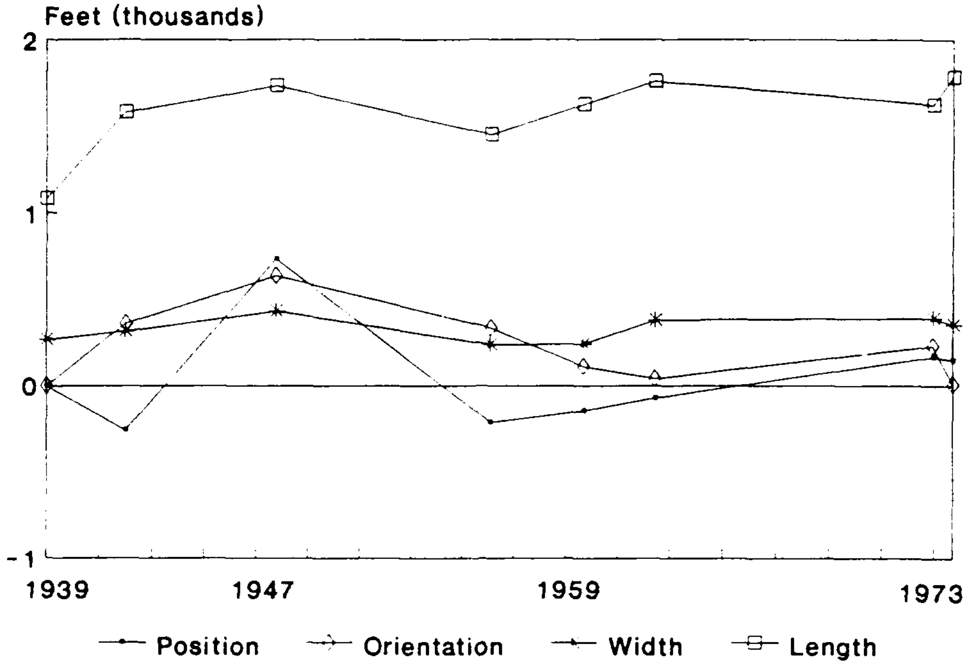
Figure C46. San Luis



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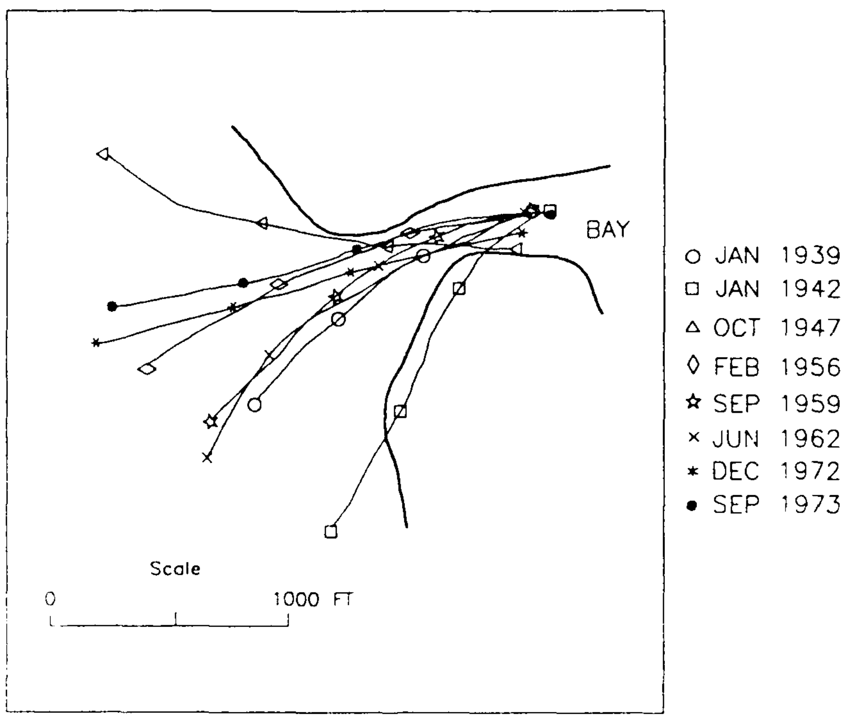
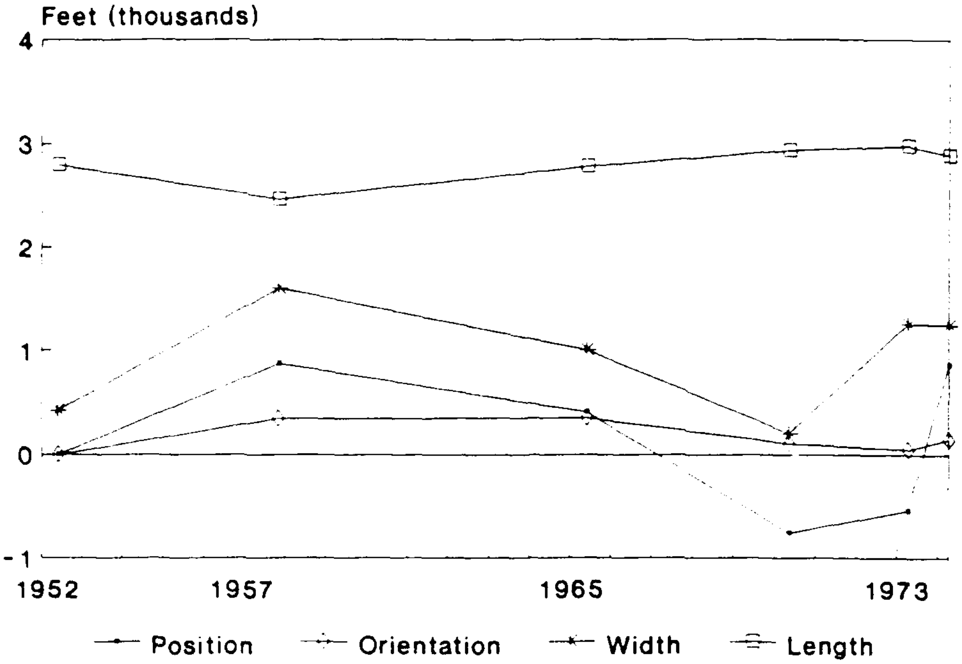
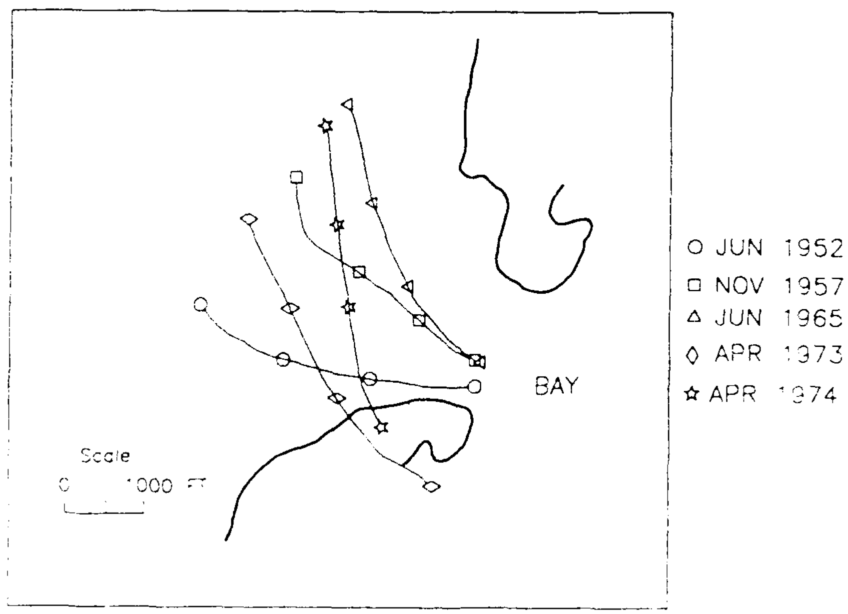


b.

Figure C47. Bolinas

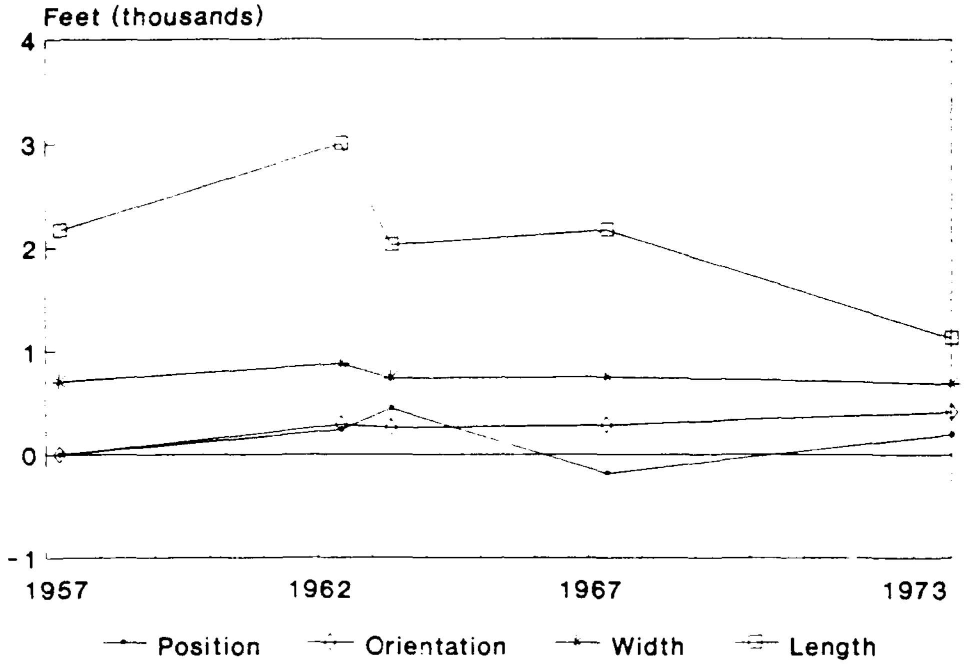


a.

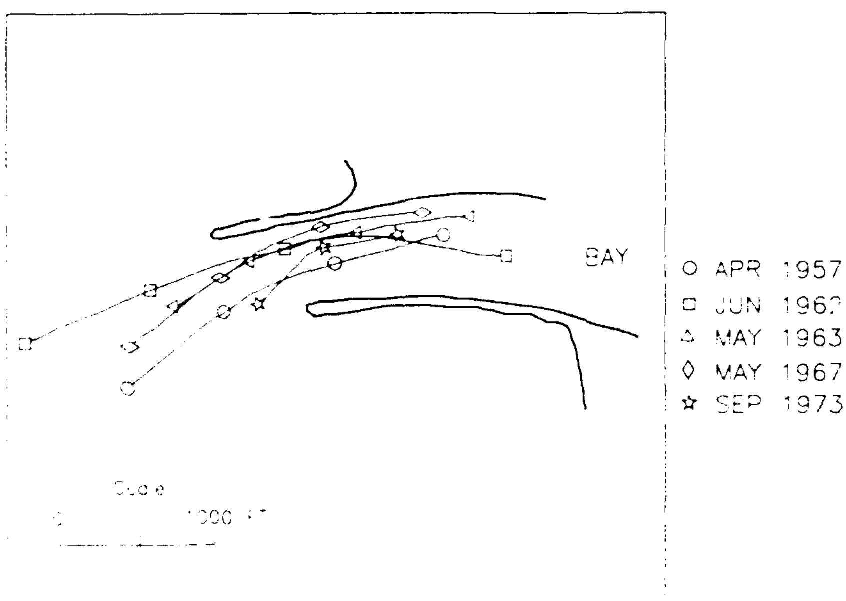


b.

Figure C48. Drakes

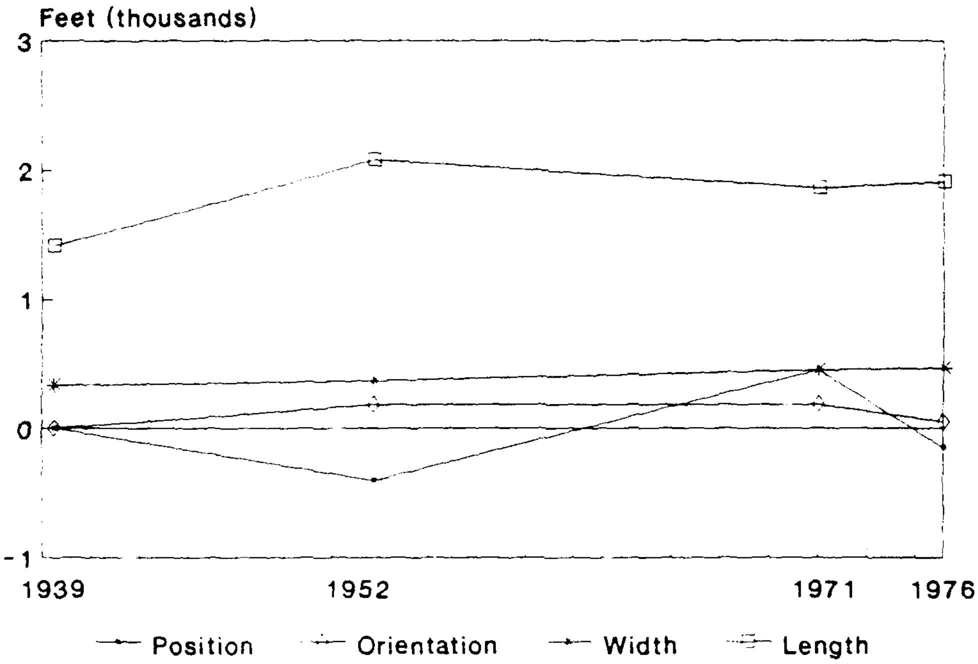


a.

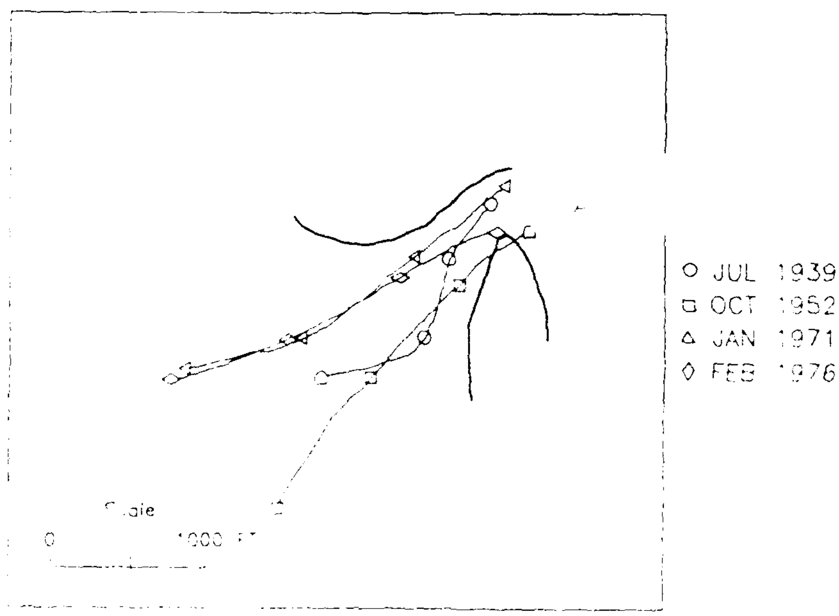


b.

Figure C49. Siuslaw

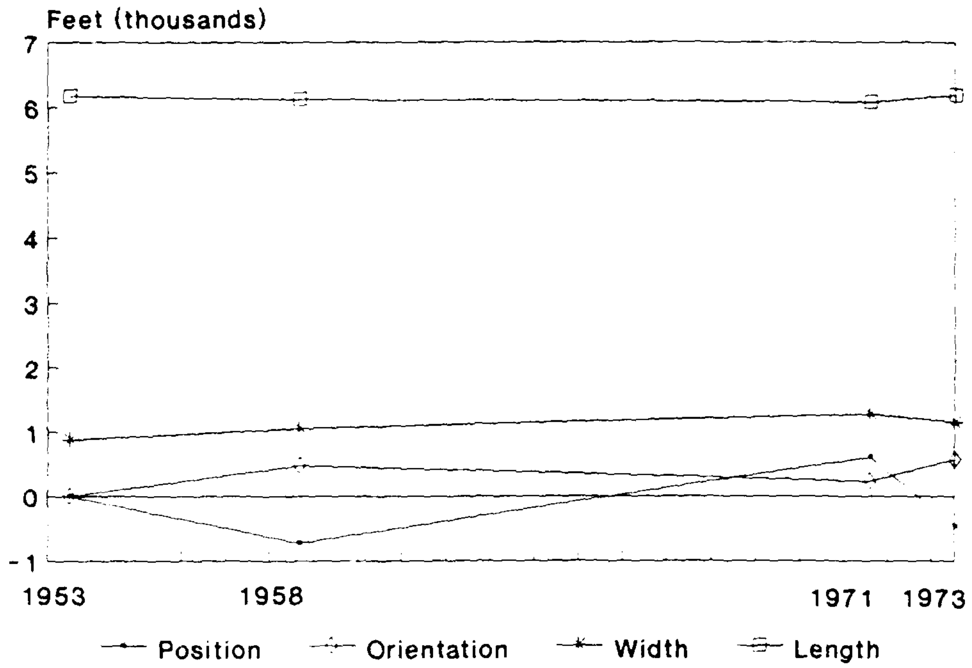


a.

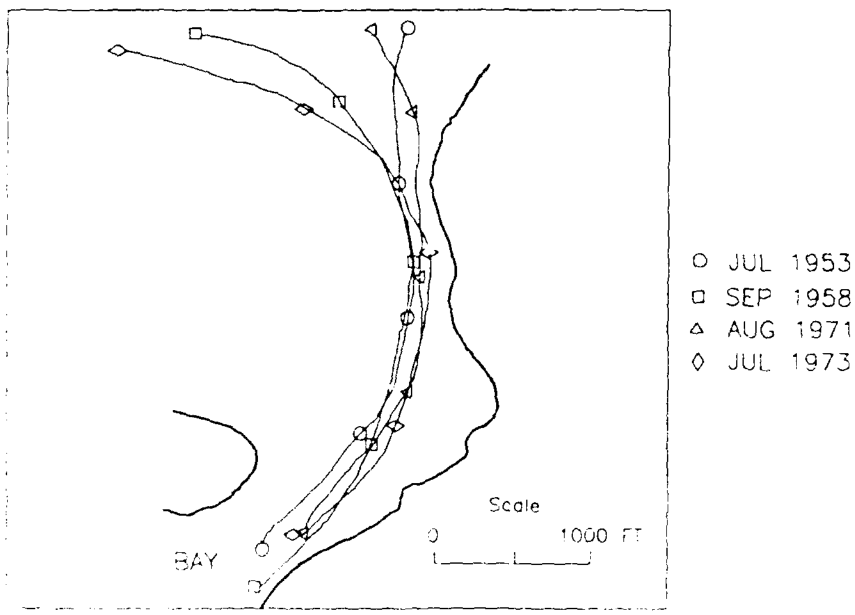


b.

Figure C50. Siletz



a.



b.

Figure C51. Netarts

APPENDIX D: NOTATION

A_C	Critical cross-sectional area
A_E	Equilibrium cross-sectional area
$\underline{D}$	N component unit vector
dL/dt	Time rate of change in inlet channel length
dO/dt	Time rate of change in inlet channel orientation
dP/dt	Time rate of change in mean inlet channel position
dW/dt	Time rate of change in inlet channel width
i	Counter increasing from 1 to N
$\underline{I}$	N component unit vector
L	Length of main inlet channel
L_t	Arc length of inlet channel at time t
$L_{t+\Delta t}$	Arc length of inlet channel at time t+Δt
max	Subscript denoting maximum value recorded
min	Subscript denoting minimum value recorded
M_{tot}	Total longshore transport
N	Number of points on channel trace
t	Time
V_{max}	Maximum velocity in inlet throat
V_T	Threshold velocity
W	Inlet width
β	Stability index as defined by O'Brien and Dean (1972)
Δ	Change in quantity
ϵ	Geographic stability index (orientation)
η	Geographic stability index (position)
ϕ_1	Relative hydraulic stability parameter (width)
ϕ_2	Relative hydraulic stability parameter (length)
Φ	Combined relative hydraulic stability parameter (ϕ_1 and ϕ_2)
ψ_1	Relative geographic stability parameter (position)
ψ_2	Relative geographic stability parameter (orientation)
Ψ	Combined relative geographic stability parameter (ψ_1 and ψ_2)